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CENTRAL BIOMASS COMBUSTION FACILITY FEASIBILITY STUDY

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July, 1982

Prepared for

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ABSTRACT

The Montana Energy and MHD Research and Development Institute (MERDI) has conducted a feasibility study of the use of crop residues (wheat straw) as an energy feedstock for a central heating plant. The feasibility study addresses the agronomic constraints to biomass production, the collection and transport of crop residues to the proposed facility, and the processing and combustion technologies feasible for the proposed facility.

The results of the study show that, over the whole state, straw is not an economic fuel to use for a central heating plant because of the agricultural needs and the collection and processing costs. However, there are probably certain regions and years where it may be collected and used economically. The study establishes the farming and equipment operational conditions necessary for the economic use of straw as a fuel. In the future, without a change in crops, farming practices, and equipment, the probability that straw can be used statewide as an economical fuel is low. It is pointed out that farm practices and equipment are available now such that in many localized remote areas straw may be used as a heat source for large farm complexes/facilities.

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.0 INTRODUCTION

As originally proposed to the Department of Natural Resources and Conservation (DNRC), this project was Phase I of an overall six-phase program which could be conducted sequentially. Phase I was a preliminary study and identification of possible critical project elements for future phases. During Phase I MERDI was contracted to perform four tasks:

1) Waste resource identification;

2) Straw collection methods;

3) Packaging and storage; and

4) Processing for combustion.

During the course of the program, MERDI accomplished each of these tasks, and has identified critical project elements for possible continuing phases.

The task of identifying the waste resource requires that for years of average crop production, a continuous supply of straw must be potentially available for a central heating facility. Certainly, in years of minimum crop yield this concept is not possible. This finding is predicated on current agricultural practices where cereal grain crops are grown as food crops and not as energy crops. If the agricultural community would decide to grow crops as energy crops then the concept might become feasible. MERDI is not necessarily recommending this change back to a larger plant (smaller head type of crop), but if that decision were made it would be more feasible to use straw as a fuel for central heating.

Initial findings indicate that it may be presently feasible to use straw as a heat source for individual home heating systems in certain areas of Montana. The Highwood Bench area is one of them. A major problem is

that MERDI has not been able to identify any home furnace completely suitable for this fuel. MERDI did, however, find two manufacturers who claim to make these furnaces and they are identified at the end of this report. We could not obtain any information pertinent to sales, performance, and economics of the units. However, it does appear that a home boiler system development supported by DNRC may be modified to use baled straw as a fuel.

The collection methods which are presently employed for straw removal are baling and stacking or collecting loose straw and piling it. The current practice utilized in straw collection is to windrow straw during the harvest operation and later return to bale it. This procedure would work technically for supplying straw to a central heating plant. However, the economics are not feasible with today's costs when the straw has to be transported more than ten (10) miles. These statements are discussed in detail in Chapter 3. Perhaps the best solution to the economics of collection and transportation costs would be to densify or cube or pelletize the straw in the field in an economic manner prior to transport. The major problem here is that no known equipment exists which will densify straw economically. The John Deere Company manufactured a hay cuber which would densify hay, but they discontinued the line. There are problems with the physical and chemical properties of straw which need to be studied prior to any economical straw cuber development. Various phenolic binding agents can be added to straw for densifying but they are presently too expensive for extensive use. Another major factor is that these processes (collection, processing, and transport) are very energy intensive and rely heavily on petroleum products. With the increasing cost of petroleum products, the future of using straw for central heating plants appears doubtful unless new equipment is developed.

To conclude this introductory section, two statements can be made concerning the use of straw as a heat source:

1) Under today's economic conditions, farming practices, and available equipment the use of straw for central heating plant facilities is not feasible; and
2) The use of straw in localized aras (such as the Highwood Bench) may be economically feasible for individual home or farm complex heating systems. However, this concept needs further analysis prior to demonstration.

The critical project elements identified which require further study are:

1) An examination of current farming methods which would identify the value and acceptability of farming for energy crops rather than food crops;
2) An investigation of home and farm sized furnaces or combustion systems which would economically use straw as a fuel;
3) An identification of all the local areas in Montana where yearly individual use of straw for heating is feasible;
4) Development of a "check-list" which individuals can use to decide whether to utilize straw for home heating;
5) An examination of the properties of straw which resist densification; and
6) Development of portable and/or stationary densification equipment which can be used for straw.

2.0 WASTE RESOURCE IDENTIFICATION

When evaluating the probable amounts of biomass (straw available in Montana counties) three factors must be considered: 1) the total amount of straw produced in an average year, 2) the amount of straw which should be returned to the soil in order to maintain soil nutrients, and 3) the fraction of total straw production that is available for energy purposes when following the best agronomic practices.

This approach is predicated on the following assumption. That straw is a by-product of cereal grain production and as such the best agronomic practices to maximize long run grain production will be followed, even if this results in the short term loss of a potential cash crop from grain residues.

2.1 Production of Straw in Montana

The quality of crop residues in a given county depends on a wide range of factors including local climatic conditions, soil type, and crop type as well as agricultural practices in that county. It is thus apparent that an inventory of residues be performed on a specific crop basis and that the inventory be based on yields in the specific area in order to compensate for differences in local climates and farming practices. In addition to the variations found as a result of regional differences there also will be secular differences in crop yields due to seasonal changes in growing seasons, moisture, and cultural practices. For the purposes of this feasibility study 36 Montana counties are examined over a period of 25 years.

The crops selected for examination in this study were limited to winter wheat, spring wheat, and barley. Other crops which produce by-products which could conceivably be used for direct combustion feedstocks include corn, flax, rye, sugar beets, and safflower. However, the by-products of these crops possess higher value as animal feed supplements and represent a very small percentage of total crop residues in Montana. Of the total crop production in Montana during the period of 1972-1976, wheat produced 76.1% of all cash receipts, barley produced 14.3%, and all other crops totaled 9.4% of cash receipts. Hay and other forage crops are excluded from the inventory because of their higher value as animal feed supplements when compared to projected fuel costs.

Two estimates of straw production are made for each county. The first of these is a weighted average of the straw production by crop in the county and the second is a minimum production figure derived statistically. The former figure is derived in the following manner:

$$\text{Average production} = \sum_{i=1}^{n} \sum_{j=1}^{3} C_{ij} \cdot Y_{ij} \cdot S_j$$

C_{ij} = acres of crop type j in year i

Y_{ij} = yield in bushels per acre for crop type j in year i

S_j = pounds of straw per bushel of yield in crop type j (Table 2).

n = number of years

Minimum yields for each county are derived in the following manner:

$$\sum_{i=1}^{n} \sum_{j=1}^{3} C_{ij} \cdot X_{ij} \cdot S_j$$

$$X_{ij} = \frac{1}{n} \sum_{i=1}^{n} Y_{ij} - 1.729 \sqrt{\frac{\sum_{i=1}^{n} (Y_{ij} - \bar{Y})^2}{n-1}}$$

Table 1 illustrates the average acreage, yield, and the standard deviation of the yield for Montana's principal crops. Table 2 lists the average straw production in pounds per bushel of yield for each of Montana's major agricultural commodities. Table 3 lists the average production of wheat straw in pounds/acre for each of Montana's major grain producing counties. Table 3 also lists the minimum expected amounts of straw produced in each county. These estimates are made at the 95% confidence level using the method described earlier. Barley straw is dropped from further consideration on the basis of the information in Table 1 and 2. The yield of straw in pounds per acre is sufficiently small to prohibit large scale collection of straw in excess of current agricultural uses for animal feed.

In addition to estimates of total biomass production in each of the counties, Table 3 lists estimates of recoverable resources for both average and minimal production years. Recoverable resources are assumed to equal one-half (1/2) of total biomass production. The rationale underlying a 50% reduction in produced biomass to recoverable biomass is found in the harvesting practices and equipment limitations. The time frame within which the harvest takes place emphasizes maximum grain harvest; this mandates minimal straw handling in order to make maximum use of harvesting

TABLE 1

AVERAGE GRAIN PRODUCTION IN MONTANA COUNTIES (1952-1977)

County	WINTER WHEAT			SPRING WHEAT			BARLEY		
	Average Acres Planted	Average* Yield/ Acre	Standard Deviation of Yield	Average Acres Planted	Average* Yield/ Acre	Standard Deviation of Yield	Average* Acres Planted	Average Yield/ Acre	Standard Deviation of Yield
Big Horn	65,169.2	26.78	6.52	4,378.3	29.31	5.15	24,876.2	34.32	7.35
Blaine	43,734.6	23.61	4.03	56,308.7	20.00	4.97	51,504.8	29.13	7.57
Broadwater	16,673.1	22.68	6.91	918.3	28.38	6.27	11,914.3	38.00	11.29
Carbon	21,765.4	25.88	5.65	4,139.1	30.05	6.77	14,876.2	39.54	9.23
Carter	14,907.7	20.25	6.67	10,730.4	15.36	6.43	7,923.8	24.31	7.70
Cascade	131,461.5	28.39	5.85	14,456.5	22.58	4.42	50,514.3	32.39	8.81
Chouteau	382,684.6	28.66	5.90	43,408.7	22.06	5.15	150,900.0	33.71	7.64
Custer	16,396.2	22.30	6.99	4,934.8	23.34	6.92	6,761.9	27.52	8.00
Daniels	6,158.3	19.03	4.88	185,847.8	19.61	5.77	42,776.2	27.80	8.52
Dawson	75,169.2	22.53	8.03	48,239.1	19.00	7.01	27,414.3	29.57	10.52
Fallon	38,573.1	20.64	9.18	38,826.1	16.92	5.96	16,323.8	26.63	7.90
Fergus	141,873.1	27.69	4.84	18,895.7	18.98	4.15	79,866.7	31.63	5.51
Garfield	24,888.5	20.39	7.82	18,687.0	16.54	6.02	12,557.1	26.33	10.18
Glacier	22,138.5	28.67	5.46	38,004.4	25.29	5.90	94,328.6	36.76	9.66
Golden Valley	18,442.3	22.26	4.64	1,165.2	18.20	4.92	5,781.0	26.15	6.02
Hill	263,276.9	24.68	4.68	120,873.9	19.00	4.55	114,385.7	29.46	7.94
Judith Basin	71,380.8	25.81	5.37	10,317.4	19.93	3.87	34,904.8	31.43	6.44
Liberty	92,469.2	24.63	7.23	91,030.4	19.72	6.91	68,695.2	29.83	10.93
Meagher	3,911.5	24.48	7.19	1,069.6	19.77	5.09	5,176.2	31.62	8.82
McCone	48,426.9	20.77	8.54	107,130.4	19.43	6.36	32,976.2	28.96	10.29
Musselshell	15,950.0	22.42	5.20	986.9	19.07	5.36	5,909.5	26.97	6.12

TABLE 1 (Continued)

County	WINTER WHEAT			SPRING WHEAT			BARLEY		
	Average Acres Planted	Average* Yield/ Acre	Standard Deviation of Yield	Average Acres Planted	Average* Yield/ Acre	Standard Deviation of Yield	Average Acres Planted	Average* Yield/ Acre	Standard Deviation of Yield
Petroleum	3,430.8	22.12	6.71	1,834.8	17.42	4.69	3,200.0	27.10	6.58
Phillips	25,430.8	22.72	6.36	69,873.9	19.82	5.33	32,895.2	30.10	8.06
Pondera	91,130.8	30.30	6.38	48,243.5	24.67	7.38	104,857.1	38.19	9.85
Powder River	26,446.2	24.93	7.81	3,491.3	17.49	5.94	5,652.4	29.81	8.81
Prairie	30,346.2	22.99	7.40	6,573.9	19.69	8.38	7,138.1	27.13	7.79
Richland	44,911.5	22.90	7.45	78,908.7	21.62	6.32	37,138.1	33.00	8.26
Roosevelt	16,384.6	21.67	7.17	238,430.4	20.68	6.06	55,866.7	29.41	8.20
Rosebud	21,492.3	23.60	7.67	5,104.4	24.98	8.13	10,938.1	33.11	9.08
Sheridan	10,572.0	21.24	5.69	149,126.1	21.43	6.00	51,757.1	30.19	9.29
Stillwater	61,984.6	25.02	6.06	1,634.8	23.33	6.95	21,338.1	30.87	6.79
Sweetgrass	7,803.9	23.24	6.04	1,921.7	21.63	5.47	8,223.8	32.94	9.24
Teton	115,334.6	29.17	5.01	35,087.0	24.20	5.60	88,642.9	38.66	8.90
Toole	53,946.2	26.14	6.52	107,747.8	21.34	7.44	111,447.6	31.54	11.07
Treasure	4,592.3	25.94	8.29	1,078.3	32.19	7.90	2,995.2	44.61	8.49
Valley	16,011.5	22.12	7.24	222,934.8	19.91	5.57	66,409.5	28.60	8.91
Wheatland	8,638.5	23.35	5.65	3,056.5	118.10	3.54	8,852.4	27.60	6.30
Wibaux	5,316.0	23.30	8.94	41,500.0	20.29	6.41	10,304.8	29.86	8.07
Yellowstone	83,126.9	26.39	5.61	5,491.3	37.83	6.15	33,071.4	38.38	7.98

* Average yield is measured in bushel per acre.

SOURCE: Compiled from Montana Agricultural Statistics, Montana Crop and Livestock Reporting Service, Helena, MT.

TABLE 2

RESIDUES PER BUSHEL OF PRODUCTION IN MONTANA

CROP	LBS.
Winter Wheat	135
Winter Rye	120
Spring Wheat	120
Spring Wheat (Semi-Dwarf Variety)	100
Spring Barley	85
Oats	60
Flax	85
Corn	90
Sorghum	100

Source: U.S. Department of Agriculture, Soil Conservation Service, Form MT-JS-ES-120, "Planning Sheet and Record of Dryland Conservation Cropping Systems".

TABLE 3

STRAW PRODUCTION IN MONTANA COUNTIES

COUNTY	AVERAGE LBS/ACRE STRAW PRODUCTION	AVERAGE LBS/ACRE STRAW RECOVERABLE	MINIMUM LBS/ACRE STRAW PRODUCTION	MINIMUM LBS/ACRE STRAW RECOVERABLE
Bighorn	3426	1713	1715	857
Blaine	2653	1326	1577	788
Broadwater	3140	1570	1457	728
Carter	2291	1145	896	448
Cascade	3472	1736	2150	1075
Chouteau	3514	1757	2220	1110
Carbon	3448	1724	2100	1050
Custer	2812	1406	1308	654
Daniels	2360	1180	1081	540
Dawson	2701	1350	1003	502
Fallon	2382	1191	761	380
Fergus	3275	1637	2265	1132
Garfield	2381	1190	805	402
Glacier	3209	1604	1824	912
Golden Valley	3691	1845	1752	876
Hill	2886	1443	1815	907
Judith Basin	3144	1572	2025	1012
Liberty	2766	1383	1165	582
Meagher	2892	1446	1466	733
McCone	2475	1237	904	452
Petroleum	2533	1266	1325	622
Phillips	2561	1280	1305	652
Pondera	4078	2039	2005	1002
Powder River	3109	1554	1424	712
Prairie	2863	1431	1225	612
Richland	2675	1337	1324	662
Roosevelt	2349	1174	1162	581
Rosebud	3018	1509	1397	698
Sheridan	2434	1217	1309	654
Stillwater	3173	1586	1868	934
Sweetgrass	2901	1450	1558	779
Teton	3509	1754	2306	1153
Toole	2716	1358	1197	598
Treasure	3607	1803	1967	983
Valley	2284	1142	1139	569
Wheatland	3799	1899	1581	790
Wibaux	2372	1186	1081	540
Yellowstone	3508	1754	2245	1122

equipment and labor. Another reason for leaving standing residues can be attributed to uneven and rocky field surfaces which cause excessive wear and damage to equipment when attempts are made to cut the straw too closely.

2.2 Soil Nutrient Maintenance

The environmental consequences of collecting small grain crop residues for use as an industrial or energy feedstock must be examined. The major environmental considerations associated with the collection and removal phase of a biomass energy program are the long-term effects on the productivity of the soil. Crop residues have long been recognized as an essential deterrent to wind and water erosion. Crop residues also contribute to soil fertility maintenance by increasing water infiltration, reducing evaporation losses, recycling of minerals and nutrients, and promotion of biological decomposition and soil aeration.

The analysis of the needed crop residues for soil nutrient maintenance is broken into three major categories; 1) soil nutrient recycling, 2) wind erosion prevention, and 3) water erosion protection. The first category is selected because of the need to replace nutrients and minerals with commercial fertilizer. The latter two categories are responsible for the largest portion of soil nutrient/fertility losses. Additionally the knowledge of the effects of excessive mulching or residue plowback are briefly summarized.

2.2.1 Soil Nutrient Recycling

The formation of organic matter in the soil is an important function

maintaining soil permeability, nutrient level, tillability, microbial levels and soil chemistry. The effects of this organic matter on biological activities within the soil is not well understood and in any event well beyond the scope and needs of this study. This study will focus its efforts on the amounts of the three primary soil nutrients - nitrogen, phosphorous, and potassium - which would be removed with the straw in the collection phase. The effects of straw mulches on water infiltration and evaporation will be discussed in a subsequent section.

Soil information is the process in which vegetation extracts chemical nutrients and water from the soil and returns the essential nutrients to the soil through a process of decay. Modern agrarian practices significantly impact this natural cycle of soil information as portions of the nutrients in the vegetation are removed with crop harvest and as modern cultivation techniques enhance soil erosion from wind and water. The nutrients in the soil lost as a result of those practices are presently being replaced with commercial fertilizers. The organic matter and trace elements removed with the harvest and crop residues are largely ignored under present practices. The replacement costs of commercial fertilizers associated with the removal of wheat straw (wheat straw represents in excess of 85% of total straw availability in Montana) represent a necessary expenditure on the behalf of the producer in order to maintain existing soil nutrient levels.

Table 4 lists the average concentration of essential elements in whole plants including those elements not normally replaced with commercial fertilizers. Table 5 shows the percentages and pounds of

TABLE 4

AVERAGE CONCENTRATION OF ESSENTIAL ELEMENTS IN WHOLE PLANTS

ELEMENT	PERCENT
Oxygen	45
Carbon	44
Hydrogen	6
Nitrogen	2
Phosphorus	0.5
Potassium	1.0
Calcium	0.6
Sulfur	0.4
Magnesium	0.3
Boron	0.005
Chlorine	0.015
Copper	0.001
Iron	0.020
Manganese	0.050
Molybdenum	0.0001
Zinc	0.0100
TOTAL	99.9011

SOURCE: Roller 1975, pg. 7.

TABLE 5

AVERAGE CONTENT OF N, P, K IN WHEAT PLANTS (LB. NUTRIENT/LB. DRY MATTER)

PART	PERCENT OF WHOLE	N	P	K
Kernels	40	.0220	.0047	.0044
Straw	60	.0067	.0008	.0087
Whole	100	.0287	.0055	.0131

TABLE 6

FERTILIZER REQUIREMENTS OF WHEAT (LB. FERTILIZER/LB DRY MATTER)

PART	PERCENT OF WHOLE	N	P_2O_5	K_2O
Kernel	40	.0052	.0022	.0032
Straw	60	.0077	.0031	.0048
Whole	100	.0129	.0053	.008

SOURCE: Grown Organic Matter as a Fuel Raw Material Resource, Roller, 1975.

nitrogen, phosphorus, and potassium normally found in wheat. Table 6 converts the elements found in wheat to fertilizer input requirements per pound of dry matter produced.

Obviously a significant amount of the nutrients (40%) are removed with the harvest of the grain. However, Roller (1975) indicates that if the residues are allowed to decompose in the field 80% of the nitrogen and all of the phosphorous and potassium in the residues is recycled. Table 7 estimates the cost of replacing those elements which would normally be recovered naturally. No costs are associated with application because some fertilization is necessary in the normal course of events. Fertilizer costs are derived from quotes offered by Montana producers and distributors of fertilizers. The cost of nutrient replacement associated with straw removal as shown in Table 7 is net of any trace minerals, credit for organic matter, and long-term intangible effects on soil tilth and productivity.

2.2.2 Wind Erosion Prevention

Nutrient losses incurred as a result of conventional tillage practices are dominated by nutrients lost as a result of erosion. In semi-arid climates similar to Montanas', the vast majority of erosion is a result of wind erosion. The role of small grain and other residues in the prevention of wind erosion has been clearly established and quantified over the past 35 years.

The most common method of estimating soil loss by wind erosion is the Wind Erosion Equation developed by Dr. W. S. Chepil. This equation

TABLE 7

FERTILIZER REPLENISHMENT COSTS PER TON OF STRAW REMOVED*

ELEMENT	$/TON	REQUIREMENT	$ TON OF STRAW
N	194	.0077	1.20
P	233	.0031	.72
K	165	.0048	.792
		TOTAL	$2.71

* 1980 Cost in Montana

quantifies the erosion expected from a given field and can subsequently be used to estimate the required amount of small grain residue necessary to keep wind erosion losses within acceptable limits.

The functional form of the wind erosion equation is:

$$E = f(I,F,K,V,M,D,R)$$

where: E is the amount of erosion measured in tons per year; I is the soil erodibility index; F is surface crust stability; K is ridge roughness; V is wind velocity; M is soil surface moisture; D is field distance; and R is vegetative cover. Vegetative cover is measured as equivalent flat small grain residues using a series of nomographs prepared by the USDA-SCS.

The measurement and development of each of these factors is time consuming and complicated. However, these factors have been condensed into standard Wind Erosion Groups (WEG) for different soil structures. Table 8 details the soil structures associated with each WEG. The number assigned to each WEG is directly related to the erodibility of the soil, e.g., WEG 1 is more erodible than WEG 2 and so on. Climatic factors for selected Montana counties are shown in Figure 1. The climatic factor for each county decreases with respect to moisture and favorable climatic conditions in that county. Climatic factors for areas smaller than counties are usually available at local soil conservation service offices.

Application of the wind erosion equation to estimate the required amount of small grain residues to maintain acceptable soil losses can be made using a series of nomographs prepared by the Soil Conservation

TABLE 8

WIND ERODIBILITY SOIL GROUPS IN THE NORTHERN GREAT PLAINS*

Group 1. Mostly dune sand; single grain structure; vegetation difficult to establish; not suitable for cropland.

Group 2. Mostly loamy sands; dry clod structure (as indicated by percentage of dry soil aggregates >0.84 mm. in diameter) is weak; requires a combination of intensive practices to control wind erosion.

Group 3. Mostly sandy loams; dry clod structure moderately stable; requires at least two measures to control wind erosion in regions with high and intermediate climatic factor.

Group 4. Mostly clays and silty clays; dry clod structure extremely variable due to contraction and swelling by freezing and thawing and wetting and drying; need a combination of at least two measures in regions with high and intermediate climatic factor.

Group 5. Mostly loams and sandy clay loams; dry clod structure quite stable; a combination of at least two measures is needed in a region with high climatic factor.

Group 6. Mostly silt loams and clay loams; dry clod structure stable; require a combination of at least two measures in a region with high climatic factor.

Group 7. Mostly silty clay loams; dry clod structure extremely stable; usually a single practice is sufficient to control wind erosion.

Group 8. Soils not suitable for crops because of wetness, stoniness, etc.

* For use in predicting soil losses by wind and determining alternative land treatments for soil protection.

SOURCE: USDA-SCS, Technical Guide, Section III-1-B-3.

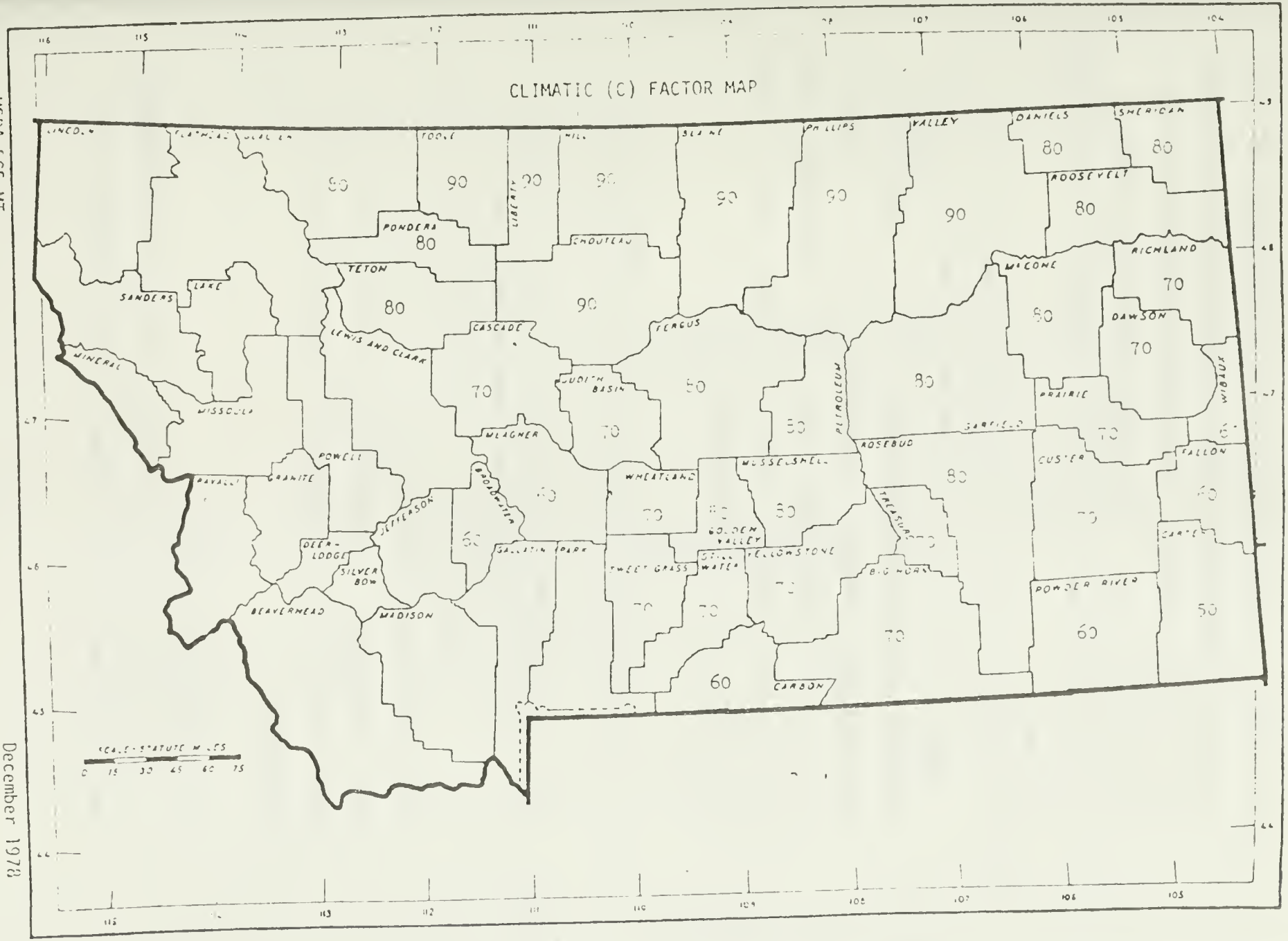

FIGURE 1.--Montana Climatic (C) Factor Map

SOURCE: USDA-SCS, Montana Technical Guide III-1-B-3

Service (SCS) for each WEG and climatic factor (see Appendix A). Use of prepared nomographs such as those provided by the SCS significantly reduce the effort required to estimate soil losses and residue cover requirements for an area. However, when applying these figures to specific fields care must be exercised to compensate for local geographic conditions.

Table 9 displays estimates of required residue cover to prevent wind erosion by WEG and climatic factors in Montana. These estimates represent minimum coverage on a standardized field with an acceptable soil loss of five tons per acre per year. This is the maximum allowable soil loss per acre recommended by the SCS in Montana. Table 10 lists the acreage by WEG in selected Montana counties.

The quantity of straw residues required to prevent wind erosion increases with respect to increased field length, windward slopes in fields, and tillage practices. The effect of various tillage practices on the residues available for wind erosion protection is shown in Table 11. For Montana counties following standard tillage practices the USDA-SCS recommends straw residues of one ton per acre be left on the field (BOWN). This figure takes into account some tillage operations and normal variations in field topography and climatic conditions.

2.2.3 Water Erosion Prevention

The prime method of erosion control from water is the establishment and maintenance of crop residues and living vegetative cover

TABLE 9

REQUIRED SMALL GRAIN RESIDUE TO PREVENT EXCESSIVE WIND EROSION (LBS/ACRE)

CLIMATIC FACTOR	WEG 1 & 2	WEG 3, 4, & 4L	WEG 5, 6, 7	WEG 8
50	1700	1200	800	800
60	1750	1400	900	900
70	1750	1500	1000	1000
80	1750+	1500	1100	1000
90	1750+	1600	1150	1000

Source: U.S. Department of Agriculture, Soil Conservation Service, Technical Guide, Section III-1 B-3, Wind Erosion.

TABLE 10

CROPLANDS BY WIND EROSION GROUP (WEG)

COUNTY	WEG 1&2 (ACRES)	WEG 3,4,4L (ACRES)	WEG 5,6,7 (ACRES)	WEG 8 (ACRES)	TOTAL (ACRES)
Big Horn	807	97,407	232,471	13,795	344,480
Blaine	0	76,465	447,864	21,846	546,175
Broadwater	0	120,519	44,504	0	165,023
Carbon	0	109,315	121,161	12,520	242,996
Carter	900	57,581	86,372	0	144,853
Cascade	2,291	345,636	212,601	2,324	562,852
Chouteau	7,533	719,896	455,879	542	1,183,850
Custer	4,871	33,087	51,922	2,029	91,909
Daniels	17,113	119,789	427,820	5,704	570,426
Dawson	0	102,000	345,000	0	447,000
Fallon	0	91,200	136,800	0	228,000
Fergus	0	245,318	299,835	0	545,153
Garfield	0	248,600	104,400	0	353,000
Glacier	100	113,315	431,750	5,000	550,165
Golden Valley	750	48,912	52,109	0	101,771
Hill	0	289,135	578,271	0	867,406
*Liberty	4,500	320,850	209,250	0	534,600
Meagher	0	4,350	82,131	600	87,081
McCone	86,218	255,725	96,000	0	437,943
Musselshell	500	33,322	50,000	0	83,822
Phillips	1,000	133,000	143,200	99,500	376,700
Pondera	56,109	252,491	22,437	28,055	561,092
Powder River	19,926	151,500	3,516	0	174,942
Prairie	78	11,725	106,100	0	117,903
Richland	6,850	18,098	433,173	690	458,811
Roosevelt	72,644	268,176	316,876	73,618	731,316
Rosebud	22,036	107,065	9,202	0	138,303
Sheridan	25,801	363,251	233,624	0	622,676
Stillwater	0	14,258	239,865	12,500	266,623

TABLE 10 (Continued)

CROPLANDS BY WIND EROSION GROUP (WEG)

COUNTY	WEG 1&2 (ACRES)	WEG 3,4,4L (ACRES)	WEG 5,6,7 (ACRES)	WEG 8 (ACRES)	TOTAL (ACRES)
Sweetgrass	900	75,900	8,000	4,500	89,300
Teton	4,200	236,650	354,800	0	653,400
*Toole	5,500	392,150	255,750	0	653,400
Treasure	12,867	23,079	1,822	0	37,768
Valley	100	145,000	578,462	0	724,462
Wheatland	0	7,384	66,462	0	73,846
Wibaux	14,672	49,731	100,198	0	164,151
**Yellowstone	0	4,000	280,816	0	284,816
***Statewide	358,266	5,811,754	7,807,245	283,223	14,270,488

* Liberty and Toole Counties are reported jointly. This number indicates the relative share held by the respective county.

** Total may not add to total lands because soil categories 1-8 do not fully represent the soil types in the county.

***For those counties listed only.

SOURCE: Compiled from USDA-SCS form SCS-IM-2, County Baseline Data on Land Use by Wind Erosion Groups.

TABLE 11

AVERAGE AMOUNTS OF STUBBLE REMAINING AFTER EACH TILLAGE OPERATION, ASSUMING THAT IMPLEMENTS ARE ADJUSTED AND OPERATED TO PROVIDE ADEQUATE TILLAGE AND MAINTAIN RESIDUES ON SURFACE

SUBSURFACE IMPLEMENTS	% STUBBLE AFTER EACH TILLAGE OPERATION
Blades (36" or wider)	90%
Sweeps (24" or wider)	90%
Rod Weeders - plain	90%
Rod Weeders - with simi-chisels	80%

MIXING IMPLEMENTS	% STUBBLE AFTER EACH TILLAGE OPERATION
Heavy duty cult. (22" sweeps)	85%
Field or duckfoot cult. (shovels or narrow sweeps)	80%
Heavy duty cult. (shovels and chisels)	75%
Disk (one-way or tandem or offset disk)	50%
Harrow (spring tooth type)	65%
Drills	85%

SOURCE: U.S. Department of Agriculture Soil Conservation Service, MT-JS-ES-120, Agronomy, (Rev.) 5/22/79.

on the soil. Additional methods of water erosion control include roughing the surface, reducing field length, terracing, and contouring fields.

The most common method of estimating soil loss by water erosion is the use of the Universal Soil Loss Equation. The functional form of the soil loss equation is, $A=f(R,K,L,S,C,P)$ where A is the completed soil loss per unit area, R is the rainfall factor, K is the soil erodibility factor, L is the slope length factor, S is the slope gradient factor, C is the cropping management factor, and P is the erosion control practice factor.

When considering the removal of crop residues from the field to use as an energy feedstock, the two factors of the soil loss equation which are variable are the cropping management and erosion control practice factors. The cropping management factor is particularly important because it relates directly to the crop residue disposal practices. Although it is difficult to evaluate the effectiveness of a crop management practice on a long-term basis due to the influence of other variable such as rainfall on residue production, it has been possible to measure the effectiveness of crop management practices over a growing season. The soil loss equation divides the year into five stages of production:

1. Rough fallow, turn plowing to seeding;
2. Seedling, seedbed preparation to one month after plowing;

3. Establishment, from one to two months after spring or summer seeding except for fall seeded crops, which include all the winter months until April or May;
4. Growing or mature crop, end of period 3 until harvest; and
5. Residue or stubble, crop harvest to plowing or new seeding.

The most notable relationship between crop management factors and erosion is the relationship between productivity and soil loss. In general, soil loss decreases as productivity increases. This is attributed to the denser forage cover and heavier crop residues associated with higher yields.

The erosion control factor is an adjustment for tillage practices such as contour plowing, strip farming, and terracing of farmlands.

Soil nutrient loss from water erosion is not a significant problem in the agricultural areas of Montana, although a few areas do experience some significant erosion. Because wind and water erosion are not mutually present at a given time the amount of residues required to prevent erosion from either cause must be sufficiently great to prevent erosion from the dominant factor; for Montana counties this dominant factor is wind erosion. As a rule sufficient crop residues to prevent wind erosion also will prevent water erosion - about one ton per acre.

2.2.4 Crop Residues and Moisutre Retention

In addition to prevention of wind and water erosion, crop residues serve to conserve moisutre in the soil. Residue mulches serve to conserve moisture from the surface and by decreasing the capillary action of the soil. Secondly, they increase soil moisture intake by slowing moisture runoff and retaining snow. Soil moisture intake is also increased by the tendency of crop residues to diffuse raindrop impact and the erosive action of the rain.

The quantity of crop residues necessary for erosion control for wind or water erosion provides sufficient residue cover to enhance soil moisture retention.

2.2.5 Detrimental Effects of Residues

The quantity of residues required for soil nutrient maintenance, erosion protection, and soil permeability vary with respect to climates, soil types, and crop production. Excessive residues incorporated into fields can have detrimental effects on productivity (FLAIM, 1979). These effects include:

1. Reduction in soil temperatures and depressed germination;
2. Reduced nitrate formation;
3. Production of substances which are toxic to new plants;
4. Increased pesticide requirements; and
5. Increased plant disease.

Experiments on winter wheat and spring wheat plots by Anderson and Russel (1964) have indicated that a mulch of 4000 pounds per acre was required to depress spring wheat production and that a mulch of 5000 pounds per acre was required to reduce production of winter wheat. Significant reductions in production were found in spring wheat at 6000 pounds per acre and in winter wheat at 8000 pounds per acre. Research on the effects of residue mulches on barley production have not been identified at this time.

The reduced yields from fields with heavy mulches are attributable to reduced soil temperatures and germination rates. Quantification of detrimental effects from the other potential problems including plant toxicity, pests, and disease have not been accomplished to date.

2.3 Available Straw Production

Previous sections have discussed the average and minimum production of straw in pounds per acre for wheat fields in Montana counties and the uses of this straw for soil maintenance and erosion control. The detrimental effects of straw residues on new crops have been briefly discussed also. The intent of this section is to reconcile the production of straw and the uses of the straw, the difference between the two representing that portion of the straw which is available for use as an energy feedstock.

This analysis of the amount of straw available focuses entirely on wheat straw production. The reasons for this are three-fold: 1) wheat represents the largest single source of crop residues in Montana; 2) the larger straw/grain ratios associated with wheat reduce the costs of collection;

and 3) barley straw has competitive uses which make it relatively more valuable than wheat straw.

The analysis also limits the uses of straw to that amount required to prevent wind erosion. This follows from the fact that wind and water erosion are not binding at the same time and place; hence the constraining factor is the one which requires the larger amount of residues. Residue requirements for other soil maintenance are sufficiently met by the straw required for erosion control. Following the assumption made earlier that cereal grain production is the primary crop to be produced and that the long-run fertility of the soil is the major constraining factor, the level of required residue cover per acre is assumed to be one ton per acre. This assumption follows the recommendations of the USDA-SCS (Bown) and the Solar Energy Research Institute (FLAIM). It should be noted that this figure is not unreasonable when compared to the requirements for the "ideal" fields of Table 9.

Table 12 compares straw production in average and minimum years to the soil maintenance requirements and calculates the net straw availability in Montana counties. The results of this comparison indicate that in average years and present crop gains a sufficient amount of straw in excess of soil maintenance requirements is available in an economically collectable volume. However, in years of low crop productivity only a small number of north central Montana counties produce enough crop residues to prevent wind erosion damage, and these counties do not produce enough excess residues to be economically collectible. This analysis leads one to the

TABLE 12

WHEAT STRAW PRODUCTION AND AVAILABILITY IN MONTANA COUNTIES (LBS/ACRE)

COUNTY	AVERAGE PRODUCTION	NET AVAILABLE	MINIMUM PRODUCTION	MINIMUM AVAILABLE
Big Horn	3609	1609	2119	119
Blaine	2744	744	1754	(246)
Broadwater	3079	1079	1486	(514)
Carbon	3511	1511	2182	182
Carter	2361	361	900	(1100)
Cascade	3720	1720	2403	403
Chouteau	3744	1744	2402	402
Custer	2961	961	1379	(621)
Daniels	2360	360	1167	(833)
Dawson	2743	743	1037	(963)
Fallon	2407	407	722	(1278)
Fergus	3566	1566	2420	470
Garfield	2423	423	848	(1152)
Glacier	3342	1342	2103	103
Golden Valley	2956	956	1879	(121)
Hill	3000	1000	1957	(43)
Judith Basin	3346	1346	2152	152
Liberty	2849	849	1291	(709)
McCone	2478	478	952	(1048)
Meagher	3104	1104	1563	(437)
Petroleum	2674	674	1317	(683)
Phillips	2562	562	1358	(642)
Pondera	3699	1699	2199	199
Powder River	3217	1217	1467	(533)
Prairie	2971	971	1246	(754)
Richland	2774	774	1311	(789)
Roosevelt	2510	510	1229	(771)
Rosebud	3149	1149	1383	(617)
Sheridan	2591	591	1343	(657)
Stillwater	3362	1362	1950	(50)
Sweetgrass	3030	1030	1677	(333)
Teton	3696	1696	2531	531
Toole	2883	883	1250	(650)
Treasure	3570	1570	1696	(304)
Valley	2429	429	1240	(760)
Wheatland	2896	896	1732	(268)
Wibaux	2515	515	1102	(898)
Yellowstone	3623	1623	2318	318

( ) depicts deficits or negative amounts of straw available.

conclusion that excess crop residues in economically collectable volumes are not available in most Montana counties on a sustained yield basis and any central heating plant could require significant quantities of supplemental fuel, e.g. coal.

However, this analysis at a county level based on average yields is not necessarily binding on areas within counties which may have exceptional yields due to irrigation or particularly favorable growing conditions. One example of a smaller area with conditions which create higher than county average yields is the Highwood Bench area in Chouteau County where there is adequate straw available for the sustained operation of a central heating plant.

3.0 COLLECTION, PROCESSING, AND TRANSPORT

This section focuses on the economic and logistics of a crop residue biomass program. The collection, processing, and transport of biomass feedstocks are a major facet of any biomass program. As a rule biomass resources are widely dispersed on a geographical basis when compared to conventional fossil fuel supplies. This geographical dispersion of biomass resources results in a major collection and transportation cost component in any large scale biomass project.

The objectives of this section are to quantify crop residue collection costs, crop residue transportation costs, and to briefly summarize the effects of technological advances in crop residue processing which may prove beneficial in the collection process. The economic analysis of the collection and transportation of crop residues is based on conventional technology.

3.1 Crop Residue Collection

The conventional technology used in the collection and storage of crop residues is to bale the straw. The equipment used to bale the straw is standard haying equipment capable of producing round or rectangular bales which vary in weight from approximately 45 pounds to an excess of 800 pounds. The square bales offer handling and shipping ease and the round bales offer economic baling and superior storage characteristics. Although it is possible to collect straw in a loose stack this process is not feasible where the straw is to be shipped any distance.

The economics of baling and stacking the straw at the edge of the field are examined for five different system configurations. These systems represent a range of different capital and labor mixes. All of the systems assume that the straw is windrowed in the field and requires no further processing beyond baling and stacking at the edge of the field. The five system configurations are:

1. A large round baler and round bale mover;
2. A tractor Power Take-Off (PTO) operated baler with a self propelled bale wagon;
3. A PTO operated baler with a PTO operated bale wagon;
4. A PTO operated baler with a manually loaded hay trailer or bale sled; and
5. A PTO operated baler with a bale accumulator attachment which uses a front end loader and trailer to move the bale.

Estimates of the total capital investment in each of the systems are found in Table 13. Table 14 estimates annual fixed costs of ownership

TABLE 13

CAPITAL INVESTMENT IN FIVE STRAW SYSTEMS

	1	2	3	4	5
100 H.P. Tractor	31,078				
70 H.P. Tractor		9,400	9,400	9,400	9,400
45 H.P. Tractor					5,290
Self Propelled Bale Wagon		29,400			
Large Round Baler	8,350				
Round Bale Mover	2,125				
PTO Baler		6,000	6,000	6,000	6,000
Hay Trailer				1,050	1,050
PTO Bale Wagon			12,500		
Bale Accumulator					3,300
Front End Loader					3,050
Bale Attachment for Loader					1,170
Capital Investment	$41,550	$44,800	$27,900	$16,450	$29,260

NOTE: An interesting side point is that all of this equipment is not common on the "average" Montana grain farm.

TABLE 14

ANNUAL OWNERSHIP COSTS OF FIVE STRAW SYSTEMS

	1	2	3	4	5
100 H.P. Tractor	6,105				
70 H.P. Tractor		1,846	1,846	1,846	1,846
45 H.P. Tractor					1,039
Self Propelled Bale Wagon		5,775			
Large Round Baler	1,640				
Round Bale Mover	417				
PTO Baler		1,178	1,178	1,178	1,178
Hay Tailer				206	206
PTO Bale Wagon			2,455		
Bale Accumulator					648
Front End Loader					599
Bale Attachment for Loader					230
Annual Ownership Costs	$8,162	$8,799	$5,479	$3,230	$5,746

for each system component. These annual ownership costs include such items as depreciation, taxes, insurance, and a return on investment. Table 15 estimates the fixed costs of production per ton of straw for each system at 100, 250, 500, and 1000 tons of production per year. These fixed costs of production will fall if the components of each system can be used for other farm operations such as haying. In this manner the fixed costs of ownership can be allocated over a larger range of production, thus lowering the per unit fixed cost of production.

Operating or variable costs for each of the five systems at production levels of 100, 250, 500, and 1000 tons per year are given in Table 16 to 19. Variable costs include fuel, lubricants, normal maintenance, materials consumed in production and labor. These estimates are taken from "Owning and Operating Costs of 8 Haying Systems" published by the Cooperative Extension Service in July 1978. Costs have been excalated to 1980 dollars by the appropriate price indexes computed by the U.S. Department of Commerce.

Table 20 estimates total costs (fixed costs plus variable costs) for processing a ton of straw and stacking it at the edge of the field. Table 21 lists the cost of processing a ton of straw by a custom or contract operator. These costs are taken from a Cooperative Extension Service Bulletin entitled "Custom Rates for Farmwork in Montana" and are adjusted for inflation. These rates are competitive with producer-owned equipment in the lower production levels.

Individuals and companies wishing to compute the fixed and variable costs of production of these existing or planned haying or straw collection

TABLE 15

FIXED COSTS OF PRODUCTION AT DIFFERENT LEVELS OF PRODUCTION ($/TON)

PRODUCTION TONS/YEAR	1	2	3	4	5
100	81.62	87.99	54.79	32.30	57.46
250	32.64	35.19	21.91	12.92	22.98
500	16.32	17.59	10.95	6.46	11.49
1000	8.62	8.80	5.48	3.23	5.75

TABLE 16

VARIABLE (OPERATING) COSTS PER HOUR AND PER TON FOR FIVE STRAW SYSTEMS
BASED ON 100 TONS PER YEAR

System	Machine	Repair Cost Per Hour	Fuel Cost Per Hour	Lubricant Cost Per Hour	Machinery Variable Cost Per Hour	Tractor Variable Cost Per Hour	Tractor & Machinery Variable Costs Per Hour	Tons Per Hour	Hours Per Ton	Tractor & Machinery Variable Costs Per Ton	Twine Costs Per Ton	Labor Cost Per Ton By Operation	Tractor & Machinery Variable Costs, Twine Cost, & Labor Cost Per Ton
		Dollars											
1	Large Round Baler	2.24	-	-	2.24	7.89	10.13	5	.20	2.02	.31	.69	
	Round Bale Mover	.55	-	-	.55	7.89	8.44	6	.17	1.43	-	.58	5.03
2	PTO Baler	1.06	-	-	1.06	2.91	3.97	6	.17	.67	.96	.59	
	S.P. Bale Wagon	3.57	3.17	.47	7.21	-	7.21	8	.13	.93	-	.45	3.60
3	PTO Baler	1.06	-	-	1.06	2.91	3.97	6	.17	.67	.96	.59	
	PTO Bale Wagon	1.63	-	-	1.63	2.91	4.54	6	.17	.77	-	.59	3.58
4	PTO Baler	1.05	-	-	1.05	2.91	3.96	6	.17	.67	.96	.59	
	Hay Trailer	.11	-	-	.11	2.91	3.02	2.7	.37	1.11	-	2.57	5.90
5	PTO Baler	1.05	-	-	1.05	2.91	3.96	6	.17	.67	.96	.59	
	Bale Acc. Att. Behind Baler	.62	-	-	.62	-	.62	6	.17	.11	-	-	
	Front-End Loader	.10	-	-	.10	4.03	4.13	6	.17	.70	-	.59	
	Bale Pickup Att. for Loader	.22	-	-	.22	-	.22	6	.17	.04	-	-	
	Hay Trailer	.11	-	-	.11	2.91	3.02	6	.17	.51	-	.59	4.76

TABLE 17

VARIABLE (OPERATING) COSTS PER HOUR AND PER TON FOR FIVE STRAW SYSTEMS
BASED ON 250 TONS PER YEAR

System	Machine	Repair Cost Per Hour	Fuel Cost Per Hour	Lubricant Cost Per Hour	Machinery Variable Cost Per Hour	Tractor Variable Cost Per Hour	Tractor & Machinery Variable Costs Per Hour	Tons Per Hour	Hours Per Ton	Tractor & Machinery Variable Costs Per Ton	Twine Costs Per Ton	Labor Cost Per Ton By Operation	Tractor & Machinery Variable Costs, Twine Cost, & Labor Cost Per Ton
		Dollars											
1	Large Round Baler	2.95	-	-	2.95	8.32	11.27	5	.20	2.25	.31	.69	
	Round Bale Mover	.72	-	-	.72	8.32	9.04	6	.17	1.53	-	.58	5.36
2	PTO Baler	1.40	-	-	1.40	3.08	4.48	6	.17	.76	.97	.59	
	S.P. Bale Wagon	4.73	3.12	.39	8.24	-	8.24	8	.13	1.07	-	.45	3.84
3	PTO Baler	1.40	-	-	1.40	3.08	4.48	6	.17	.76	.97	.59	
	PTO Bale Wagon	2.15	-	-	2.15	3.08	5.23	6	.17	.89	-	.59	3.80
4	PTO Baler	1.40	-	-	1.40	3.08	4.48	6	.17	.76	.97	.59	
	Hay Trailer	.13	-	-	.13	3.08	3.21	2.7	.37	1.19	-	2.57	6.08
5	PTO Baler	1.40	-	-	1.40	3.08	4.48	6	.17	.76	.97	.59	
	Bale Acc. Att. Behind Baler	.82	-	-	.82	-	.82	6	.17	.14	-	-	
	Front-End Loader	.21	-	-	.21	4.10	4.31	6	.17	.73	-	.59	
	Bale Pickup Att. for Loader	.30	-	-	.30	-	.30	6	.17	.05	-	-	
	Hay Trailer	.11	-	-	.11	3.08	3.19	6	.17	.54	-	-	4.96

TABLE 18

VARIABLE (OPERATING) COSTS PER HOUR AND PER TON FOR FIVE STRAW SYSTEMS
BASED ON 500 TONS PER YEAR

System	Machine	Repair Cost Per Hour	Fuel Cost Per Hour	Lubricant Cost Per Hour	Machinery Variable Cost Per Hour	Tractor Variable Cost Per Hour	Tractor & Machinery Variable Costs Per Hour	Tons Per Hour	Hours Per Ton	Tractor & Machinery Variable Costs Per Ton	Twine Costs Per Ton	Labor Cost Per Ton By Operation	Tractor & Machinery Variable Costs, Twine Cost, & Labor Cost Per Ton
		Dollars											
1	Large Round Baler	3.61	-	-	3.61	9.00	12.61	5	.20	2.52	.31	.69	
	Round Bale Mover	.89	-	-	.89	9.00	9.89	6	.17	1.68	-	.58	5.78
2	PTO Baler	1.72	-	-	1.72	3.30	5.02	6	.17	.85	.96	.59	
	S.P. Bale Wagon	5.83	3.17	.47	9.47	-	9.47	8	.13	1.23	-	.45	4.08
3	PTO Baler	1.72	-	-	1.72	3.30	5.02	6	.17	.85	.96	.59	
	PTO Bale Wagon	2.65	-	-	2.65	3.30	5.95	6	.17	1.01	-	.59	4.00
4	PTO Baler	1.72	-	-	1.72	3.30	5.02	6	.17	.85	.96	.59	
	Hay Trailer	.15	-	-	.15	3.30	3.45	2.7	.37	1.28	-	2.57	6.25
5	PTO Baler	1.72	-	-	1.72	3.30	5.02	6	.17	.85	.96	.59	
	Bale Acc. Att. Behind Baler	1.00	-	-	1.00	-	1.00	6	.17	.17	-	-	
	Front-End Loader	.36	-	-	.36	4.18	4.54	6	.17	.77	-	.59	
	Bale Pickup Att. for Loader	.36	-	-	.36	-	.36	6	.17	.06	-	-	
	Hay Trailer	.13	-	-	.13	3.30	3.43	6	.17	.58	-	.59	5.16

TABLE 19

VARIABLE (OPERATING) COSTS PER HOUR AND PER TON FOR FIVE STRAW SYSTEMS
BASED ON 1000 TONS PER YEAR

System	Machine	Repair Cost Per Hour	Fuel Cost Per Hour	Lubricant Cost Per Hour	Machinery Variable Cost Per Hour	Tractor Variable Cost Per Hour	Tractor & Machinery Variable Costs Per Hour	Tons Per Hour	Hours Per Ton	Tractor & Machinery Variable Costs Per Ton	Twine Costs Per Ton	Labor Cost Per Ton By Operation	Tractor & Machinery Variable Costs, Twine Cost, & Labor Cost Per Ton
		Dollars											
1	Large Round Baler	4.49	-	-	4.49	10.17	14.66	5	.20	2.93	.31	.69	
	Round Bale Mover	1.08	-	-	1.08	10.17	11.25	6	.17	1.91	-	.58	6.42
2	PTO Baler	2.12	-	-	2.12	3.77	5.89	6	.17	1.00	.96	.59	
	S.P. Bale Wagon	7.18	3.17	.47	10.82	-	10.82	8	.13	1.41	-	.45	4.41
3	PTO Baler	2.12	-	-	2.12	3.77	5.89	6	.17	1.00	.96	.59	
	PTO Bale Wagon	3.26	-	-	3.26	3.77	7.03	6	.17	1.20	-	.59	4.34
4	PTO Baler	2.12	-	-	2.12	3.77	5.89	6	.17	1.00	.96	.59	
	Hay Trailer	.20	-	-	.20	3.77	3.99	2.7	.37	1.48	-	2.57	6.60
5	PTO Baler	2.12	-	-	2.12	3.77	5.89	6	.17	1.00	.96	.59	
	Bale Acc. Att. Behind Baler	1.25	-	-	1.25	-	1.25	6	.17	.21	-	-	
	Front-End Loader	.63	-	-	.63	4.24	4.87	6	.17	.83	-	.59	
	Bale Pickup Att. for Loader	.44	-	-	.44	-	.44	6	.17	.07	-	-	
	Hay Trailer	.16	-	-	.16	3.77	3.93	6	.17	.67	-	.59	5.51

TABLE 20

TOTAL COST OF COLLECTION IN THE FIELD ($/TON)

	100 TONS PER YEAR				
SYSTEM	1	2	3	4	5
FIXED	81.62	87.99	54.79	32.30	57.46
VARIABLE	5.03	3.60	3.58	5.90	4.76
TOTAL	86.65	91.59	58.37	38.20	62.22

	250 TONS PER YEAR				
SYSTEM	1	2	3	4	5
FIXED	32.64	35.19	21.91	12.92	22.98
VARIABLE	5.36	3.84	3.80	6.08	4.96
TOTAL	38.00	39.03	25.71	19.00	27.94

	500 TONS PER YEAR				
SYSTEM	1	2	3	4	5
FIXED	16.32	17.59	10.95	6.46	11.49
VARIABLE	5.78	4.08	4.00	6.25	5.16
TOTAL	22.10	21.67	14.95	12.71	16.65

	1000 TONS PER YEAR				
SYSTEM	1	2	3	4	5
FIXED	8.62	8.80	5.48	3.23	5.75
VARIABLE	6.42	4.41	4.34	6.60	5.51
TOTAL	15.04	13.21	9.82	9.83	11.26

TABLE 21

CUSTOM RATES FOR STRAW BALING IN MONTANA

	$/BALE	$/TON
Rectangular Bales	.37	18.50
Round Bales	6.50	18.30

Based on spring prices for 1979, estimates for 1980 are approximately 25% higher.

SOURCE: Custom Rates for Farmwork in Montana, Cooperative Extension Service, Bozeman, Montana.

systems are encouraged to use the free AGNET computer system available through the Cooperative Extension Service and their county extension agent. The system has easy to use computer programs for computing fixed costs, variable costs, and custom operator rates.

3.2 Crop Residue Transportation

The previous section discussed the costs of processing the straw and stacking it at the edge of the field. This section will examine the logistics and economics of transporting the straw to a central combustion facility. The logistics problem of transporting and storing sufficient quantities of straw for a central heating system is one of transporting a widely dispersed resource of low mass density (approximately eight pounds per cubic foot) over secondary road systems.

The geographical distribution of the resource requires that the collecting and transport equipment be highly mobile and also results in an increasing mean travel distance as the quantity of the resource demanded increases. The significance of this can be seen when one compares biomass to conventional fuels. Oil and natural gas are transported through geographically fixed pipelines and quantity is easily varied by pressure changes. Oil and natural gas also are shipped in one direction and incur no additional costs of "deadheading" or non-productive transportation costs. Coal incures the non-productive transport costs but is not subject to variations in haul distances because of the quantities of the resource in a singular geographic area.

The problem of geographical distribution is compounded by the low mass density of the straw material. Baled straw has a weight of approximately eight pounds per cubic foot of mass. This compares with a weight of 44 to 54 pounds per cubic foot of coal. Assuming an equivalent heat value for coal and straw it is necessary to handle and store approximately six (6) times the volume when utilizing straw as a fuel. The low bulk density of straw creates an additional economic burden on the transport of the straw. The vehicular transport which is necessary for the straw collection is capacity limited with respect to vehicle size and weight. When hauling straw the limitation is load size and when hauling coal the limitation is weight. Again assuming equivalent heat values for coal and straw, the straw incurs a significantly higher transportation cost per ton. The economic burden of increased handling and transport are further increased when the more probable higher heat value per ton of the coal is recognized.

Secondary roads pose a major logistics problem to straw collection and transport processes. Most county roads in Montana are not paved and are not constructed for heavy transport equipment. Subsequently there are seasonal blockages of roads, weight limitations on bridges, and heavier traffic on roads which are not designed for that traffic. An extensive straw collection process would conceivably result in an additional tax burden on county residents as these secondary roads are improved or as maintenance needs increase. The existing road system will mandate a larger than usual quantity of straw reserves at the point of combustion in order to compensate for vagaries in the weather.

Transportation costs per ton of straw have been estimated on the basis of a ten (10) mile mean haul distance. Ten miles have been estimated to be the bare minimum mean haul distance required to supply a small central heating plant. This estimate assumes a very well developed road network and average yields of straw, all of which is harvested for the proposed heating plant.

Table 22 lists three estimates of transportation costs for baled straw. The first estimate is taken from "Custom Rates for Farmwork in Montana" by the Cooperative Extension Service, the second is from a study entitled "Owning and Operating Costs of Eight Haying Systems" published by the Cooperative Extension Service, and the last is an estimate provided by a major trucking firm active in hay and straw hauling.

3.3 Business Aspects of Collection and Transport

The economies of scale in the collection and transport economics of straw tend to lead one to the conclusion that central ownership and management of the straw collection process would be the most economic. However, the physical environment and the economics of farm operations lead one to the conclusion that dispersed collection is the most economic and practical of the business alternatives for straw collection. The physical restrictions which suggest a large number of collectors instead of central collection are weather conditions which mandate rapid collection and baling and the relatively short time frame before the fields are replanted. For a central agency to own and operate the collection system, it would need to own a large amount of equipment which would be idle most of the year. However, the nature of farm operations allows the individual to capture some of the economics of scale

TABLE 22

TRANSPORTATION RATES FOR BALED STRAW ($/TON-MILE)

ESTIMATE SOURCE	$/TON
Custom Rates for Farmwork	1.18
Owning and Operating Costs	.82
Lott Track Lines	1.00
Average	$1.00

NOTE: The Independent Truckers Association estimate the costs of operating a truck at 99.7¢ per ton-mile.

utilizing a portion of the equipment in the collection system for other uses.

Ownership and operation of the transportation system differs significantly from that of the collection system. The economies of scale available from the transportation of larger amounts of straw, the need for a reliable and responsive transport network, and the ability of a central operator to use specially designed equipment all reflect advantages of centrally-owned and operated transport system. This sytem would be more readily able to amortize the costs of new technological changes in transportation such as an economical means to increase the density of the straw product - e.g., cubing - and thus lower the unit costs of straw transportation.

4.0 COMBUSTION TECHNOLOGIES

Previous sections have discussed the agronomic uses and production of straw and the collection, processing, and transport of the straw to a central facility. This section is directed at an assessment of the characteristics of straw as a fuel, alternative combustion technologies, and a brief analysis of the storage and processing requirements which would be unique to a straw fuel system.

4.1 Combustion Characteristics of Straw

Wheat straw has a number of desirable characteristics as a fuel, the most significant of which is the absence of sulfur thereby removing the need for flue gas scrubbing. Other desirable characteristics of straw as a fuel include minimal amounts of ash and a relatively high heat rate per pound (approximately 7500- Btu/lb) when compared to most refuse systems.

The drawbacks to straw as a fuel include an affinity to moisture which requires sheltered storage, the low mass density of straw which necessitates large fuel delivery systems, and a particulate emission problem which will require particulate removal systems. Table 23 shows the results of a laboratory analysis on a typical sample of straw. A subsequent analysis of a one year old straw sample indicates that the heat rate varies about 5 % from 7718 Btu/lb to 7279 btu/lb.

4.2 Solid Fuel Combustion Technologies

The Center for Energy Studies at Kansas State University (Wareham) has evaluated five combustion technologies which appear feasible for the mass firing of a solid fuel such as straw. Four of these are stoker and grate technologies and the fifth is a Fluidized Bed Combustor (FBC). The four stoker/grate technologies are:

1. Chain-Grate and Traveling-Grate Stokers;
2. Spreader Stoker and Dump or Traveling Grate;
3. Water-Cooled Vibrating-Grate Stoker; and
4. Reciprocating Grate.

Of these four types of stokers, the spreader stoker is probably the most widely used in the capacity range of 75,000 to 400,000 lbs. of steam per hour due to its rapid response to load swings and its ability to burn a variety of fuels.

Traveling-grate stokers, including those known as chain-grate stokers, consist of links, grates, or keys joined together to form a continuous

TABLE 23

WHEAT STRAW FUEL CHARACTERISTICS*

Moisture	10.0%
Carbon	43.3%
Hydrogen	5.3%
Oxygen	36.2%
Nitrogen	0.9%
Sulfur	0.1%
Ash	4.2%
TOTAL	100.0%

Heat Value	7000-7500 Btu/lb

*Some variation is to be expected between species of wheat and geographical areas.

grate or steel belt. This belt or grate rotates through the furnace on sprockets or return bends located at the front and rear of the furnace. The fuel is fed onto the traveling grate from a storage hopper located at the front of the furnace. The fuel flow rate is determined by a metal plate at the bottom of the fuel hopper which is adjusted to allow the required amount of fuel to be fed onto the traveling grate. As the layer of fuel on the grate is fed into the furnace, it is heated by radiation from the furnace gases and then ignited. The fuel continues burning as the grate travels across the furnace floor until the leftover ash is discharged at the opposite side of the furnace. Overfire air must be used in addition to that flowing up through the grate to insure proper mixing of volatile gasses to give complete combustion and provide better efficiency.

Traveling-grate stokers are capable of burning a wide variety of fuels. Almost any solid fuel, including peat, lignite, sub-bituminous coal, anthracite, and coke breeze, as well as some biomass fuels can be burned on a grate as long as they are of a suitable size. Hogged wood chips, refuse, bark and pelletized biomass fuels would probably burn well on a traveling grate although it might be necessary to co-fire with other fuels to maintain a more constant flame and heating rate.

As mentioned before, the spreader-stoker is probably the most commonly used type of stoker in the middle capacity range. The spreader-stoker is capable of burning a wide range of coals as well as bark, bagasse, wood chips, and certain pelletized biomass fuels. Lighter fuels such as straw, sawdust, and shredded refuse burn well if fed pneumatically. The spreader-

stoker is used in conjunction with either a dump grate or a traveling-grate. A spreader-stoker is made up of a series of spreader paddles that are attached to a rotating shaft, all of which is located below the fuel hopper. The fuel drops into the spreader and is then thrown by the distributer into the furnace. The smaller particles of fuel burn in suspension and the heavier particles are projected to the back of the furnace where they fall on the traveling grate. These heavier particles form a thin quick-burning bed of fuel on the grate which moves toward the front of the furnace in order to give the fuel time to completely combust before being dumped into the ash pit. Alternatively, lighter fuels may be propelled pneumatically by air or steam instead of being distributed by paddles. Air, as with the chain grate stoker, is blasted in above the fire to create turbulence and promote complete combustion of all particles and gasses.

Particulate collection equipment must be used with systems that utilize partial suspension burning. This is due to the fact that there is a greater carry-over of particulate matter in the flue gas than in other stoker systems. The collection equipment should be arranged so that the coarse carbon-bearing particles can be returned to the furnace for further burning while the fine particles are discharged to the ash removal system.

Although the burning of 100% by-product waste fuel is possible, it is usually supplemented by an auxiliary fuel such as coal, oil, or natural gas in order to maintain combustion. Alternatively, by-produce waste fuel can be used as an auxilliary fuel to burn with main fuels to help reduce the use of natural resources.

A successful substitute for older dump grates is the water-cooled vibrating-great stoker, which consists of a tuyere surface mounted on a grid of water tubes interconnected with the boiler circulation system for cooling. The water tubes are utilized as support tubing as well as acting as an economizer to raise the temperature of the feedwater. The entire structure is supported on flexing plates which allow the grid and grate to move with a vibrating action. The water-cooled vibrating-grate stoker can be used with a feeding hopper where the coal or fuel is conveyed directly onto the grate. The fuel gradually moves down the inclined grate, where the ash from the burned fuel is discharged into a pit.

More commonly the water-cooled vibrating-grate is used with a spreader stoker. The fuel is fed into the spreader mechanism where it is thrown into the furnace by distributors. The fine particles burn in suspension and coarse particles fall to the grate where combustion is completed. Again the heavy particles move down the grate by vibration and the ash is discharged into a pit.

One other type of grate being used to burn refuse or cellular by-product waste is the reciprocating grate. Instead of using a spreading principle, this method uses a mass burning principle, where all of the refuse is burned directly on the grate. The burned-out residue is discharged at the edge of the grate. This type of burning requires no prior preparation of the refuse, which is fed into a charging hopper which runs into the front of the furnace, and is discharged onto the front of the grate. Alternate rows of grates are connected to a power source and move back and forth across the face of the stationary rows.

Overfire air jets are located above the grate to provide turbulence and to assure complete combustion of the fixed carbon. Combustion air is distributed evenly to the underside of each grate to provide uniform cooling of the grates.

A recently developed technology that is being used to produce energy more efficiently is the Fluid Bed Combustor (FBC). It can be used in burning coal, municipal refuse, and straw, as well as other various organic materials. The FBC consists of a bed of sand into which is passed a sufficient volume of air to unlock, boil, and mix the sand. The sand does not reach a liquid state, but is hot enough to ignite the fuel.

There are several ways to introduce the fuel into the system. When coal is used as the fuel, limestone or dolomite is used instead of sand. This results in the sulfur being absorbed by the limestone or dolomite, producing a cleaner flue gas. The coal is injected into the fluid bed where combustion takes place. The hot gasses produced from the combustion are then used to produce steam or some other useful energy source. Although most of the ash is removed by recycling the bed material, some ash escapes from the bed and must be cleaned up with a particulate removal system. Research is presently being done on fluid bed combined cycle power plants which could run gas turbines and steam turbines.

Another application of the fluid bed combustor is the burning of organic waste by-products. Sand can be used as a bed material due to the low sulfur emissions of most waste by-product fuels. The fuel is shredded

and sized and then fed into the top of the FBC. The large particles achieve combustion in the bed, and smaller particles and volatiles burn in the vapor space above the bed. The produced gas is then used to produce steam for heating or to generate electricity.

4.3 Facility Sizing and Cost Estimates

The sizing of a boiler for a central heating facility is a very site and application specific task. However, a number of general design criteria should be considered at any site. These include the peak heating load to be served, the potential for system growth, any diminished productive capacity over the lifetime of the plant, the need for system redundancy, and the efficiency of the distribution system.

Peak load sizing requires that the plant have sufficient capacity to meet the maximum daily load on the system. Although very site and application specific, peak loads for residential applications in north central Montana have been estimated in the following manner. The Idaho National Engineering Laboratory has estimated heat loss factors for homes in the northern tier to be 12,000 Btu/hr for new energy efficiency homes, 28,800 Btu/hr for average homes in the housing stock, and 48,000 for poorly insulated and constructed homes. Havre, Montana had a heating degree day requirement of 1,528 degree days during January 1978. This results in an average heat maintenance requirement of approximately 61,000 Btu/hr for the month of January for the average home in the housing stock. Diurnal or daily peak heating requirements are estimated at 120% of the average monthly requirement or 73,200 Btu/hr. The need to design the heating facility around the peak daily load on the system rather than average loads has a tendency to create

excess capacity; however thus excess capacity problem can be resolved through off peak sales to interaptable customers, e.g. warehouses or shop facilities.

Some potential for system growth should be accommodated for in the system design. This growth can be attributed to natural growth phenomena, changes in lifestyles, depreciation of the housing stock, and any number of other variables. This study assumes a 10% excess capacity requirement for growth potential.

The system design also must consider the potential for diminished generating capacity in the system as the system nears its productive lifetime. This diminished capacity can be partially offset through system maintenance procedures, but some erosion in generating capacity is inevitable. This study assumes that 10% of the generating capacity of the system will be lost as the system depreciates.

The system design also must consider the efficiency of the delivery system which transfers the heat from the boiler unit to the ultimate consumer. Heat losses in distribution significantly reduce the systems capacity to meet peak heating requirements. This study assumes a very efficient state of the act distribution system with a net 10% loss.

The system also must have sufficient redundancy in generating capacity to meet the majority of the peak heat load in the eventuality of a forced outage on one or more of the boiler units. The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) recommends system

diversity coefficients in the 60% to 90% range. System diversity coefficients are the ratios of measured peak load to the sum of installed productive capacity.

Using the design criteria examined here, it is estimated that a properly designed system cannot exceed a peak load of 60% of installed capacity. A town of 1500 people has approximately 500 residences using 1970 census figures on household size. To meet the heating requirements for a town of 1500 people a boiler with an installed capacity of approximately 60,000 pounds of steam (@ 1150 Btu/lb) per hour is required. Additions of commercial, schools, public buildings, or other non-residential applications will mandate a larger system or fewer residential applications. With the 60,000 pound per hour system it will be possible to service approximately 500 average housing units plus some interruptible non/peak customers.

Costs for the combustion units and boilers were solicited from numerous boiler manufacturers (see Appendix for listing). The costs of a system in the 60,000 pounds of straw per hour range do not appear to vary much from technology to technology. These costs average $20 per pound of steam for the furnace and boiler unit. Emissions control equipment, buildings and tertiary equipment were estimated by the suppliers to be an equivalent investment. Thus, the total cost of an installed boiler (60,000 lbs/hr capacity) would be approximately $40 per pound of productive capacity or $2.4 million for a one boiler unit in order to meet suggested system design requirements for redundancy two furnace and boiler units should be employed.

4.4 Storage and Processing Requirements

Previous sections have addressed the processes and economics of baling the straw and of the transportation of the baled straw to a central facility for combustion. This section will discuss the on site storage, handling, and processing requirements of a steam generation system capable of producing 60,000 pounds of steam per hour utilizing straw as the fuel feedstock.

The storage and handling system should be designed to :

1. Provide a reasonable amount of protection for the unprocessed material;
2. Permit sufficient storage to allow for fluctuations in the delivery system (given Montana weather patterns a minimum of 10 days must be allowed);
3. Include internal transport devices to move materials from storage to processing and processed straw to the boiler; and
4. Have sufficient capacity in the system to be operative in the event of a partial failure of equipment.

The system must be capable of handling a very large volume of materials on a sustained basis with sufficient reliability to insure a continous supply of fuel to the burner. If the straw is assumed to have a heat value of 7500 Btu/lb and an average density of eight pounds per cubic foot, a very efficient boiler in the 60,000 pounds of steam per hour range would require 5.6 tons of straw per hour as fuel. This translates to 134.4 tons per day or 1400 cubic feet per hour, 33,600 cubic feet per day, over 12 million cubic feet (49,000 tons) annually at full production. If this quantity of

straw were stacked in one place the stack dimensions would exceed 230 feet on each side and 230 feet high. The base of the stack would require approximately 1 1/2 acres. The quantity of straw required will vary with respect to length of the heating season and off season industrial sales. It must be noted that the decrease in the total quantity of straw will not reduce the peak capacity necessary in the delivery system and that the average price per million Btu's of heat will vary inversely with a decrease in total heat output.

Kansas State University has designed a straw handling system which will meet these specifications. This system assumes that the farmers will bale and deliver the straw to the plant. The plant will provide truck unloading devices, raw fuel storage, grinders, processed fuel storage, and transfer devices for materials once delivered. The delivery equipment includes an overhead crane and a loader, storage is in metal buildings and silos, grinding is accomplished using tub grinders and materials are transported via pneumatic devices. Table 24 shows the estimated capital costs of each of the components and Figure 2 and 3 illustrate the delivery system.

The cost estimate of 2.3 million dollars for the straw handling system is in addition to the cost of the coal handling system required for those periods when sufficient straw is not available. Thus if coal is the alternative fuel straw must be sufficiently cheaper to amortize the additional capital required for the straw handling system or a means of converting the straw to a material with properties similar to coal at a cost competitive with coal must be designed.

TABLE 24

CAPITAL COST ESTIMATES FOR A STRAW STORAGE AND DELIVERY SYSTEM

1.	Baler	Provided and employed by private Sector
2.	On Site Storage	Provided by private sector
3.	Transportation	Provided by private sector
4.	Weighing Station	$ 60,412
5.	Truck Tipping Station	$ 25,573
6.	Multiram Unloading System	$852,183
7.	10 Day Storage for Unprocessed Straw	
	A. Butler Buildings 120'x450'x20	$288,500
8.	Unprocessed Straw Handling Equip.	
	A. Front-end loading tractor	$ 13,271
	B. Bearclaw Crane	$ 55,392
9.	Tubgrinders	
	A. Farmhand Tubgrinder 900-B	$ 12,694
10.	Grinding Pit	
	A. 2000 yds. of concrete	$ 63,470
11.	Pneumatic Transfer System #1 (From grinding pit to processed straw storage)	
	A. Rader Corp.	$ 80,780
12.	3 Day Processed Straw Storage	
	A. Atlas Corp.	$810,858
13.	Pneumatic Transfer System #2 (From processed straw storage to boiler)	
	A. Rader Corp.	$ 40,390
	ESTIMATED CAPITAL COSTS	$2,329,000

SOURCE: Kansas State University, Wheat Straw Collection and Preparation System Capital Costs.

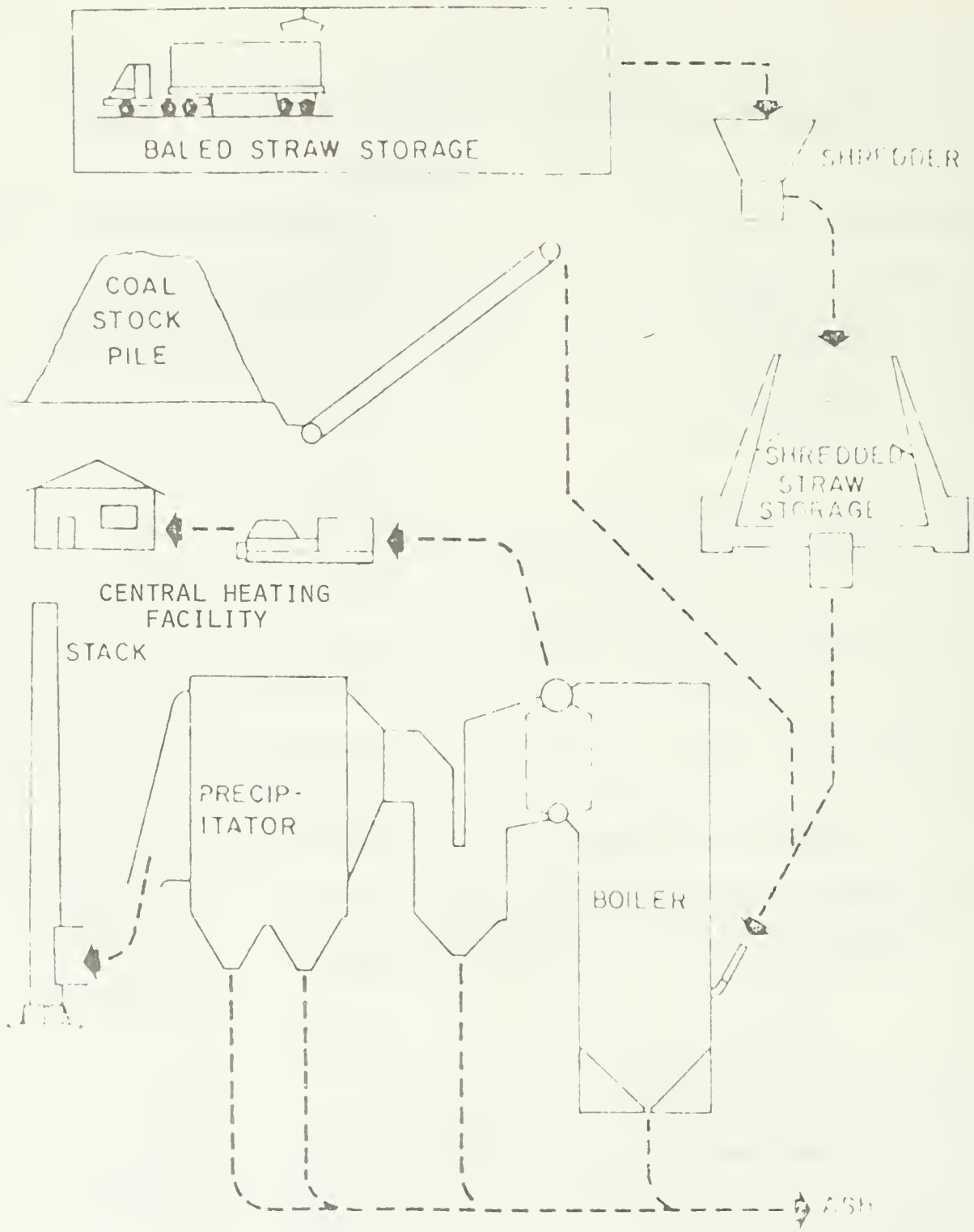

FIGURE 2.--Wheat Straw Energy System

SOURCE: "The Design of a Bulk Handling and Storage System for Biomass," Kansas State University, Report CES-74, M.E. Elkins

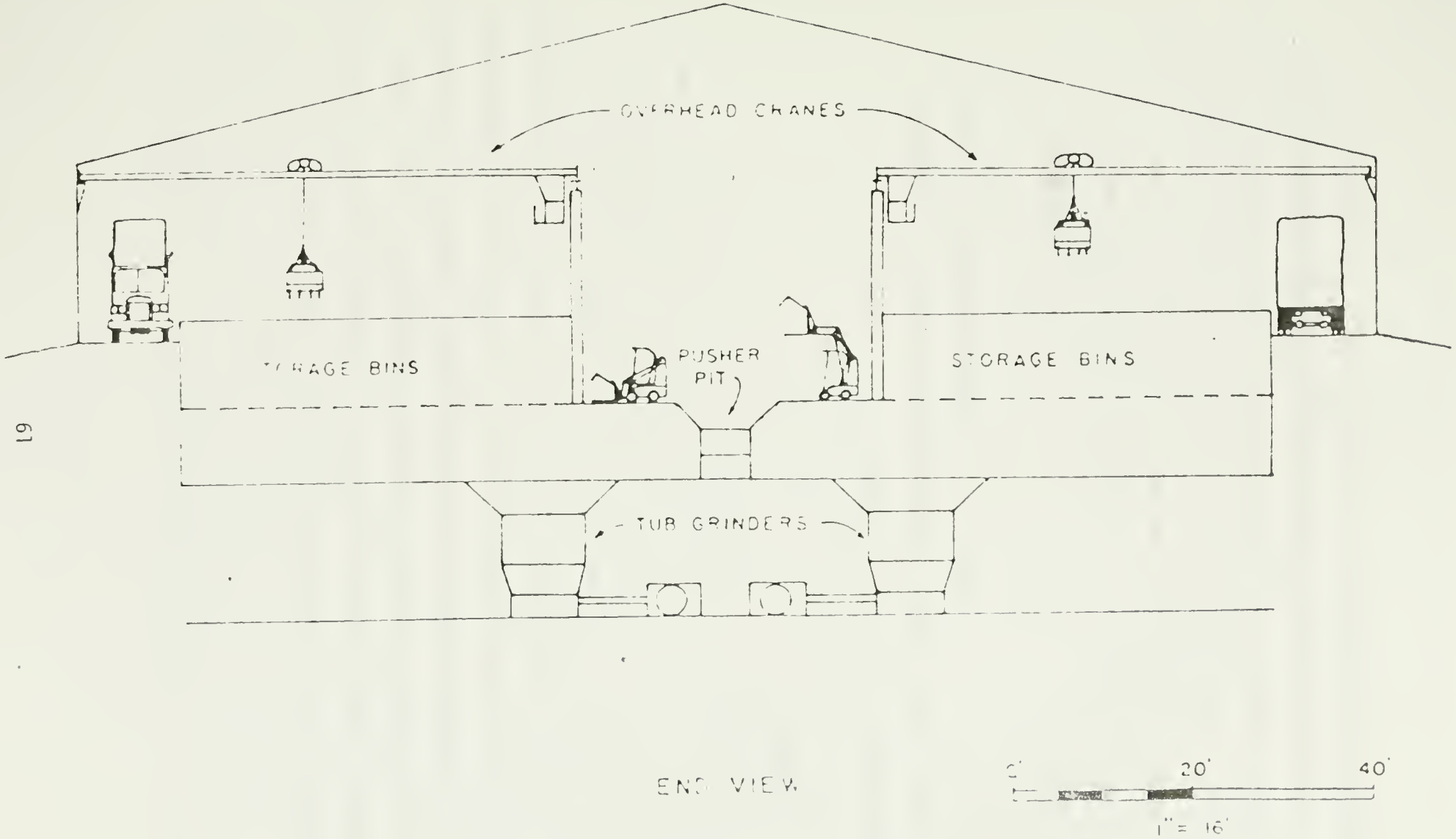

FIGURE 3.--Unprocessed Straw Storage

SOURCE: "The Design of a Bulk Handling and Storage System for Biomass," Kansas State University, Report CES-74, M.E. Elkins.

5.0 SUMMARY AND CONCLUSIONS

Individual sections of this feasibility study have addressed the agronomic, collection,, transportation, processing, and combustion of straw as a fuel. Each of these sections has addressed both the technological processes and the economic parameters which influence the use of the straw as an energy feedstock. The findings of these analyses are that while technologically feasible the use of straw as an energy feedstock is not an economical one. Furthermore the economic parameters which are constraining in the present will become more restrictive rather than less with the passage of time. Each of these constraints will be briefly summarized in this section.

5.1 Agronomic

Section 2.0 analyzes the agronomic constraints on straw as an energy feedstock. These constraints included production levels in both average and low yield years, the quantity of residues required for the prevention of wind and water erosion, the recycling of nutrients, and the formation of soil tilth. The underlying assumption upon which the analysis is predicated is that the long-term productivity of the soil is the constraining factor, and that actions which would be detrimental to this would not be economical - e.g., removing straw at the expense of wind erosion. This analysis indicates that in normal years there is an excess of straw over the requirements for erosion protection. Unfortunately in low yield years this surplus of straw is not present. Thus, the supply of straw is subject to cyclical interruption due to productivity constraints. Given the nature of weather patterns this shortage may well extend beyond a one year period.

The presence of a biomass combustion facility which would purchase straw as an energy feedstock has the potential to result in long-term soil productivity losses in these low yield years. This potential increases as farmers who have experienced a low income due to reduced grain production attempt to maintain their income by removing and selling the crop residues at a time when sufficient crop residues are not available for both sale and soil maintenance.

5.2 Collection and Transportation

Section 3.0 analyzes the technologies and economics of five straw collection systems and the costs of transporting sufficient quantities of straw from the field to a central collection point. Table 25 summarizes the costs of each of these systems (based on 1000 ton per year), the transportation costs, the fertilizer replacement costs, and adds in a small allowance for return on investment for the farmer. Table 25 also compares the delivered cost per million Btu's of straw to that of a million Btu's of coal. The price of coal was established by obtaining an estimate of the delivered price of coal in large quantity at Fort Benton, Montana. Given the accuracy of the numbers in Table 25 the delivered cost of coal and straw are essentially equal. However differences in price between coal and straw as an energy feedstock are expected to occur over time. This occurs as the price of the liquid fuels necessary for the collection, transport, and fertilizer replacement increase the price of straw relative to the price of coal. The projected coal mining activities in Montana will increase coal availability and reduce transportation costs for coal, both of which should increase the cost differences between coal and straw as a feedstock.

TABLE 25

DELIVERED COST/TON FOR STRAW

SYSTEM	1	2	3	4	5
Collection (Table 20)	15.04	13.21	9.82	9.83	11.26
Transportation (Table 22)	10.00	10.00	10.00	10.00	10.00
Fertilizer Value (Table 7)	2.71	2.71	2.71	2.71	2.71
Return to Farmer	5.00	5.00	5.00	5.00	5.00
Delivered Price/Ton	32.75	30.92	27.53	27.54	28.97
Delivered Price/MMBTU Straw	2.18	2.06	1.83	1.84	1.93
Delivered Price/MMBTU Coal	1.78	1.78	1.78	1.78	1.78

NOTE: Winter prices for wheat straw in Montana averaged $22.50 ton FOB the field.

At the present time the bulk of the coal mined in Montana is mined in the southeastern corner. However, there is a very high probability that coal will be mined in the Great Falls area of north central Montana, sufficient reserves and past mining activities indicate probable development of coal in the areas of Belt, Conrad, and Havre in north central Montana and Roundup in south central Montana. If these existing mines were to reopen to supply the demands of central heating plants the transport distance of coal could be significantly reduced.

5.3 Processing and Combustion

Section 4.0 analyzes the combustion characteristics of straw, combustion technologies, and the storage and processing requirements for a small commercial boiler system. This section also analyzed furnace systems capable of burning a range of solid fuels including coal because of the necessity for alternative fuels to biomass during those years when biomass is not available in sufficient quantities. This need for an alternative fuel requires additional storage and processing facilities which result in redundant capital and increase the costs of energy from the proposed plant. The need for an alternative fuel source may also increase the costs of pollution control if the alternative fuel is coal. Straw requires particulate emission control but does not require flue gas scrubbing. This advantage would be lost if burned in conjunction with coal.

5.4 Business Pragmatism and Straw as a Fuel

The use of crop residues as an energy feedstock has a number of major drawbacks from the perspective of the pragmatic investor including expense, uncertainty in supply, and the engineering problems of handling a high-

volume low-density product. Of these barriers the engineering problems are the most easily overcome. The problem of supply uncertainty and the logistics of purchasing small amounts of fuel from a large number of suppliers rather than a large amount of fuel from one supplier add a premium on the cost of straw as a fuel. This premium grows with the risk the entrepreneur must bear on a questionable transportation network. Current U.S. energy policies further compound the handicap borne by straw. The Fuel Use Act of 1978 prohibits the use of natural gas as the alternative fuel, thus removing the economic advantage of the low sulfur straw. This results from the need to have a secondary fuel system for a solid such as coal instead of a fluid or gas. Present policies to utilize coal will develop a superior coal delivery system and reduce the cost and uncertainty of coal as opposed to straw. Finally the present trend is to minimize the use of liquid fuels such as gasoline, diesel, and natural gas. A straw project would be heavily dependent on these fuels for the collection and transport of the straw. Present uncertainties in the supply and prices of these fuels will prevent the rational investor from using a product such as straw.

6.0 STRAW FUEL AND FARM USERS

One of the most interesting facets of the biomass feasibility program has been a growing conviction that, while not economically viable as a fuel for central heating plants, straw may be an excellent fuel source for smaller dispersed users. Small users such as a farmer with a limited need for space heat or occassional process heat for grain drying are faced with somewhat different constraints than larger industrial users.

Farmers can overcome the secular shortage of straw by selectively baling sheltered areas, bottom lands, and by baling strips of straw. Practices which would significantly increase the costs of transportation and collection for large users. The collection costs of straw can be arguably reduced for the farmer who would have idle equipment otherwise and the transportation distances would be very minimal and easily accomplished in otherwise idle time. Processing costs are unknown but storage would be a much lesser problem. Combustion by products and pollution abation equipment would usually not be necessary because of the smaller scale of operations. Ironically the element which is most critical in the central heating plant scenario - transportation - is critical also in the case of the small user of straw. However, in the case of the dispersed user this transportation problem makes the straw more attractive rather than less. With very few exceptions farmers are dependent on liquid fuels delivered by truck. Because of their relative size they do not recognize any economies of scale in this transport. This transportation and scale problem make straw relatively more attractive to dispersed agricultural users.

MERDI has been able to identify two manufacturers of small straw burning furnaces, but has not been able to ascertain the scale or economics of their products to date. Individuals interested in small straw furnaces may do so by contacting the following manufacturers:

Mid-State Manufacturing Company
Columbus, Nebraska

or

A.F. Petersens Maskinfabrik
Nordhavnsvej 4
6100 Hadeslev
Denmark

The Montana Department of Natural Resources and Conservation (DNRC) has funded a high efficiency wood boiler project which may offer an opportunity for conversion to straw as an energy feedstock.

7.0 RECOMMENDATIONS

The results of this study have led us to a fork in the road toward the utilization of agricultural residues as a heat source. The path toward central heating facilities is one for which the utilization technology is feasible, but the collection, processing, and transportation constraints are economically unfavorable. Not only are they unfavorable, but they will continue to become worse as petroleum product prices increase. The other path is toward the individual or small-scale user for home heating. For the individual user the collection, processing, and transport conditions may be economically favorable in some local areas of the state. The problems associated with this type of use are primarily with the utilization equipment necessary for combusting the straw. This may be overcome by the development of an economical home size furnace for combustion of straw.

Therefore, based on the results of this project, it is recommended that the following steps be considered for utilization of straw in Montana:

1) Proceed no further with the central heating facility concept unless drastic changes take place in present farming practices;
2) Identify specific areas of Montana where individual use may be feasible;
3) Develop a "check list" for individuals to use when deciding whether to use straw for home heat;

4) Initiate a study to identify home furnaces which can use straw as fuel; and

5) Develop a home heating system for straw fuel.

The recommendations lay the foundation for continuing this project toward a second phase as proposed in the original proposal. The major difference, however, is that the ultimate use of the straw is not for large-scale central heating facilities, but is for small-scale individual home or ranch size systems.

APPENDIX A

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APPENDIX B

MANUFACTURER CONTACTS

energy

The Montana Energy and MHD Research and Development Institute, Inc.

Post Office Box 3809
Butte, Montana 59701

(406) 494-6100
FTS 587-6100

January 18, 1980

Gentlemen:

The Montana Energy and MHD Research and Development Institute (MERDI) is currently conducting a feasibility study for the direct combustion of biomass (straw) in central heating facilities.

Thus far in our studies we have identified sufficient quantities of straw in close proximity to population centers and industrial concerns which may wish to use the straw as a primary feedstock for a steam generator. The next step in our study process is the identification of existing processes and equipment which might be utilized in the combustion process. To this end we are contacting firms such as yours in order that we might obtain accurate and reliable information.

We are specifically interested in the combustion characteristics, maintenance requirements, and estimates of installed costs of any steam generators in the 20,000 - 50,000 lb/hr range which your firm feels could handle straw as a primary feedstock.

Sincerely,

Charles F. Crane
Economist

CFC:bd

Agnew Environmental Products Co.
P.O. Box 1168
Grants Pass, OR 95726
(503)479-3396

American Fy-Feeder Engineers
1265 Rand Road
Des Plaines, IL 60016
(312)298-0044

Atlas Boiler and Equipment Co.
W 29 Spokane Falls, Blvd.
Spokane, WA 99211
(503)747-6001

Automated Combustion
P.O. Drawer 9
Lake Oswego, OR 97034
(503)636-4569

Babcock and Wilcox Company
305 Norton Bldg.
Seattle, WA 98104
(206)622-1496

The Bigelow Company
P.O. Box 706
New Haven, CT 06503
(203)772-3150

Herman Bogot and Company
3143 N. Nottingham
Chicago, IL 60634
(312)637-6037

Bumstead-Woolford Co.
P.O. Box 448
Woodinville, WA 98072
(206)485-9646

Burt Power Inc.
6405 New Tampa Hwy.
Lakeland, FL 33802
(813)876-5329

Combustion Engineering Inc.
700-112th Avenue, NE
Bellevue, WA 98004
(206)455-3030

Detroit Stoker Company
Monroe MI 48161
(313)241-9500

Energy Control Engineering Corp.
P.O. Box 3064
Charlotte, NC 28203
(704)375-1701

Envirometrix, Inc.
4725 University Way NE
Seattle, WA 98115
(206)524-6350

European Woodworking Machinery Co.
P.O. Box 452
Franklinton, NC 27525
(919)494-7455

Far Western Equipment & Chemical Co. Inc.
7327 NE 27th Ave., P.O. Box 11211
Portland, OR 97211
(503)287-4712

Foster Wheeler Corp.
P.O. Box 807
Bellevue, WA 98009
(206)454-7955

The Gaskell Company, Inc.
P.O. Box 13225
Memphis, TN 38113
(901)775-3222

Harvey Eng. and Mfg. Corp.
Route 2, Box 478
Hot Springs, AR 71901
(501)262-1010

Industrial Burner
24 West Third Ave.
Spokane, WA 99204
(509)747-7965

Irvington-Moore Division of USNR
P.O. Box 40666
Jacksonville, FL 32203
(904)354-2301

Johnston Boiler Co.
300 Pine St.
Ferrysburg, MI 49409
(616)842-5050

E. Keeler Co.
238 W. Street
Williamsport, PA 17701
(814)326-3361

Kipper and Sons Engineers, Inc.
2616 Western Ave.
Seattle, WA 98121

Lasker Boiler and Engr. Corp.
3201 S. Wolcott Ave.
Chicago, IL 60608
(312)523-3700

Mardee, Inc.
3129 E. Washington Ave.
Madison, WI 53704
(608)244-3331

The McBurney Corporation
P.O. Box 47848
Atlanta, GA 30362
(404)448-8144

McConnell Industries
P.O. Box 26210
Birmingham, AL 35226
(205)942-3321

Mechanical Equipment Company
7212 Woodlawn Avenue, NE
Seattle, WA 98115
(206)523-8526

Moore-Oregon-Canada
P.O. Box 4208
Portland, OR 97208
(503)286-8231

Peabody Gordon-Piatt, Inc.
Box 65 0
Winfield, KS 67156
(316)221-4770

Riley Stoker Corp.
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Lafayette, CA 94549
(415)284-2610

John Rogers Company, Inc.
4605 Illinois Ave.
Louisville, KY 40213
(502)458-5400

Steel Craft Corp.
Box 12408
Memphis, TN 38112
(901)452-5200

Woodamation, Inc.
P.O. Box 1365
Chalmette, LA 70044
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Wyatt Engineers, Inc.
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York, PA 17405
(717)843-8831

energy

The Montana Energy and MHD Research and Development Institute, Inc.

Post Office Box 3809
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(406) 494-6100
FTS 587-6100

January 23, 1980

Gentlemen:

The Montana Energy and MHD Research and Development Institute (MERDI) is currently conducting a technical and economic feasibility study of the direct firing of biomass (straw) in commercial boiler systems.

One of the major obstacles identified thus far in our study is the collection, transportation and processing of the straw product. In an attempt to obtain reliable information on the available equipment capable of processing and storing straw and similar agricultural products, we are contacting farm implement manufacturers such as yourself.

Would you please send me any information you have available on equipment you currently market or plan to market which you feel would be amenable to large scale straw collection. We are specifically interested in the economic aspects of collection such as equipment costs, operating and maintenance costs, production levels and special handling which may be necessitated by the processing.

Thank you very much for your assistance in this matter. If you have any questions please write or call me at (406) 494-6231.

Sincerely,

Charles F. Crane
Economist

CFC:bd

J.A. Freeman and Son
2034-T N.W. 27th Ave.
Portland, OR 97210
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Implement Division
LaPorte, IN 46350
(219)326-7777

Allis-Chalmers
Implement Division
1235 Wooley Road
Oxnard, CA 930030

John Deere
Ottumwa, IO 52501
(575)684-4641

International Harvester
401 W. Michigan Ave.
Chicago, IL 60611
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Hesston, KA 67062
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Owatonna Manufacturing Company
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402 E. 6th St.
Vinton, IO 5 2349

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North Chicago, IL 60064

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Des Moines, IO 50315

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Twin City Airport, MN 55111

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4201 N. 26th St.
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P.O. Box 865
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Hopkins, MN 55343

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1000 W. Cherokee
Sioux Falls, SD 57104

APPENDIX C

CONSULTANT REPORT

BRELSFORD ENGINEERING
P.O. BOX 1252 · 315 HAGGERTY LANE · BOZEMAN, MONTANA 59715 · (406) 587-8486

WHEAT AND BARLEY STRAW

ENERGY PRODUCTION AND SOIL CONSERVATION

Prepared for:

Montana Energy and MHD Research and Development
Institute, Inc.
Butte, Montana
MT DNRC RAE 303-78-2

Prepared by:

Brelsford Engineering, Inc.
Bozeman, Montana

March 31, 1980

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INTRODUCTION

In general, one ton of crop residue per acre of dry land grain production will provide good protection from soil erosion by wind and/or water. However, any nutrients lost by crop residue removal must be replaced to maintain soil fertility and crop productivity on a continuing basis. Minimum crop residue requirements depend on climatic conditions, soil types, rainfall, wind regimes, previous erosion and other factors.

Many soil conservation scientists agree that the amount of residue "available" as a biomass energy resource is determined primarily by tillage practices, and not by soil nutrient resource limitations. For example, a recently reported crop residue harvest study (7) indicated that about 60% of all crop residues produced in dry land production in north-central Oklahoma are "available" as a biomass energy feedstock with conventional tillage, and 80% are available with conservation tillage. Crop residue "availability" is defined by the U.S. Soil Conservation Service as the amount of residue that can be removed without exceeding "soil loss tolerance limitations."

TECHNOLOGY AND WHEAT YIELDS

For most of this century agricultural researchers have been conducting agronomic studies to devise ways, means and systems for stabilizing and increasing crop yields in the semi-arid Great Plains region, which includes Montana east of the Rocky Mountains. This climatically hazardous region regularly experiences high wind velocities, low humidity, extreme temperatures, high evaporation, and low, erratic annual precipitation, ranging from 12 to 22 inches.

Research data and experience (8) suggest that five requirements must be met to improve water conservation and erosion control in the wheat-fallow system:

- -Weed control for the entire fallow period (harvest to planting) is essential.
- -Stubble must be left standing over-winter.
- -Straw mulches must be left on the soil surface during the warm season.
- -Hard soil clods 0.4 to 3.2 inches in diamater must be left on the soil surface during the warm season.
- -Soil must be managed to retain enough water in the seedbed to germinate seeds.

Meeting these requirements maximizes soil water storage and the retention of nitrate nitrogen in the soil, reduces to near zero the potential for soil erosion, and minimizes the energy required and other crop production expenses.

Weed Control

Unwanted vegetation in fallow stubble includes grassy and broadleaf weeds, both cool and warm season species, and some volunteer wheat. Until recently, weed control began during early to mid-spring, using various tillage implements. Tillage, however, results in a water loss, by evaporation of 0.2 to 0.3 inches

per operation. Experimentation with herbicides, particularly post-harvested treatment in new wheat stubble, gained momentum as broader spectrum contact and preemergence herbicides became available. Weed control with herbicides does not disturb the soil, but to be effective herbicides must kill unwanted vegetation rapidly and completely.

Standing Stubble

Snowfall catchment by stubble is an important water source during the fallow season. Measurements show that 35 to 55 percent of water recharge during fallow is from snowmelt in stubble, which together with snowfall on planted wheat the second winter, accounts for a major portion of the region's wheat production. Storage efficiency of snowmelt is high in undisturbed stubble. Consequently, destroying fall weeds by disking is detrimental. Water saved by controlling weeds with a disk is more than offset by the water loss from snow blowoff caused by lack of stubble. Undisturbed wheat stubble with chemical fallow holds more snow, reduces runoff, and suppresses evaporation at the soil surface.

Straw Mulch

Development of modern, high-clearance, V-blade "sweep" implements and rodweeders with attached semi-chisels (tongs), in combination with greatly increased power, has made stubble mulching a widely accepted tillage practice. By absorbing raindrop impact, mulches help prevent puddling and facilitate water infiltration. Mulches also reduce evaporation by insulating the soil from the sun's energy and by decreasing wind speed at the air-soil interface.

Soil Clods

Only a small amount of fine, moist soil is needed around a wheat seed for germination. Surface clods resist wind erosion, help anchor mulches, slow runoff water, provide shade, and physically protect young plants.

However, they do not provide a good medium for weed seed germination. Straw mulches assist in the formation of non-erodible soil aggregates by providing binding agents, such as fats, waxes, and oils.

These requirements for improving water conservation and erosion control in the winter wheat-fallow system has gradually been integrated into new fallow systems. There is now less reliance upon mechanical tillage during the spring and summer months. The fallow system now extends from harvest to planting, when using minimum tillage and no-till fallow systems.

Conservation Fallow

Minimum tillage implies the application of contact and preemergence herbicides shortly after wheat harvest to kill all weeds and to inhibit any weeds or volunteer wheat from germinating until late the following spring. One sweep operation and one or two rodweedings (semi-chisel attached) usually are required until planting in early September. A variation of minimum tillage involves a single fall sweep plus a preemergence herbicide, usually Atrazine.

A no-till fallow system relies entirely on herbicides throughout the fallow season. Minimum disturbance of stubble and maximum control of weeds offers the ultimate in water storage, double that of conventional spring mechanical fallow. Wind erosion threats are nearly eliminated. No-till could conceivably be used for fallow for two consecutive seasons in regions severely affected by prolonged drought. Also, wheat yields increase with a significant reduction in energy expenditure.

Use of herbicide weed control (chemical fallow) in both minimum and no-till systems is gaining momentum commercially each year. Minimum tillage implies the use of herbicides in fallow from wheat harvest until late succeeding spring, followed by two or three mechanical tillage operations to the end of fallow in early September. No-till fallow uses herbicies only throughout the entire fallow season.

Some of the present use limitations on herbicides, such as the types available, where and when they can be applied, the costs, and the systems of application, should be worked out gradually within environmental protection guidelines and regulations. Interest is high in this form of technology because of the potential for reducing tillage and soil erosion, saving energy, and increasing crop yields substantially. Additional technical improvements can be expected with chemical fallow, use of fertilizers, and improved wheat varieties.

Although straws, stalks, and similar crop residues comprise up to 30% of the total annual biomass residue generated in the U.S., they have seldom been considered as potential renewable energy resources. About 2 to 4 ton/acre of crop residues are ordinarily produced by cereal crops and 1 to 2 tons/acre are recoverable as clean, dry, biomass. At harvest, the moisture content of cereal grain straw is the lowest of any crop residue at 10 to 15%. Corn stalks generally range up to 30%. Like most agricultural residues, straws and stalks must be harvested separately from the main crop and consequently carry their own cost of collection, transportation and storage.

Existing baling and field handling equipment is available that will approach the critical load density of 16 lb/cu. ft. (6). At this bale density, a fully loaded transport truck is at its maximum legal weight. Thus for the economic transportation and storage of seasonally produced residues, no further densification is necessary and a year-round short-haul, 12 month, commercial supply could be established for approximately \$30/ton or about \$2.40/10^6 BTU. Reduced tillage or conservation tillage practices in conjunction with residue mulches are the most effective means of maintaining a high level of soil productivity and reducing soil losses.

SOIL FERTILITY CONSTRAINTS

USDA Study

A team of U.S. Department of Agriculture scientists has determined where abundant crop residues are produced, the amounts of nutrients they contain, the effect of their removal on wind and water erosion and water runoff, and where they can safely be removed without undue damage to the soil and environment in general (11). Crop residues include small grain straw. All plant parts not sold as grain are considered residue. It can be assumed these plants parts could be harvested. In some cases improved harvesting equipment is needed.

The value of crop residues for fertility maintenance and erosion control is well documented for all agricultural regions in the United States. Crop residues contribute to soil fertility maintenance by increasing water infiltration, reducing evaporation losses, recycling minerals and nutrients, and promoting biological decomposition and soil aeration. Biological activities are very important in soil formation, and physical and chemical weathering of substrate materials replenishes some nutrients lost by residue removal.

Removal of agricultural residues and total harvesting schemes tend to reduce the generally beneficial, natural replenishment of organic matter that decaying residues provide the soil. Crop residues remaining on open farmland may play a major role in preserving moisture content and protecting the soil from wind and water erosion. Their removal could possibly deplete the organic soil content which aids the internal binding of the soil.

The USDA soil scientists research shows that after several years of leaving high quantities of wheat straw on the surface, both available nitrogen and phosphorus in the soil may be increased (8). This indicates, they explain, that no-till systems may eventually provide a higher level of inherent soil fertility than those systems in which residues are buried because a larger nutrient reservoir is established. They say, however, that fertilizer require-

ments for no-till systems may be as high or higher than those for other residue management systems because yield potential is often greater as a result of better water conservation, which in turn means greater crop-plant growth and greater fertilizer needs.

In the opinion of a MSU Cropping Systems Specialist, Dr. Grant Jackson, there is some feasibility for harvesting excess straw for fuels in Montana, since irrigated small grain production areas and many dryland wheat production areas of Montana have excess crop residue. "The prevention of reduced long-term soil productivity should be the major concern in harvesting crop residues. Although the fertilizer value of barley and wheat straw is indicated to be low, their organic content is generally beneficial for maintaining soil conservation tilth and permeability," he has said (6).

Nutrients in Crop Residue

Crop residues contains plant nutrients that must be replaced if the residues are removed from the field. Removal of crop residues will increase wind and water erosion, and the eroded sediment will carry plant nutrients with it (1). The combined nutrient removal in residues and erosion under existing cropping practices would be greater in the Corn Belt than in the Great Plains.

In soil formation, native vegetation extracts chemical nutrients from the soil and returns these essential elements to the surface soil as above-ground vegetation decays. Over thousands of years, this process develops naturally fertile surface soils. The prairie soils of the Midwest, for example, were the result of a continuous recycling and concentration of chemicals essential to plant growth. Crop residues are a source of essential plant food elements as shown on Table 1. Higher rates of commercial fertilizer are required when residues are harvested and removed from the field. A substantial portion of what is currently considered to be grain crop residue, such as wheat and barley straw, may potentially become a profitable energy resource and cash crop for the grain producer. The income derived could be used to properly conserve and adequately fertilize for grain crop production.

Table 1

AVERAGE CONCENTRATION OF
ESSENTIAL ELEMENTS IN WHOLE PLANTS

Element	Percent
Oxygen	45
Carbon	44
Hydrogen	6
Nitrogen	2
Phosphorus	0.5
Potassium	1.0
Calcium	0.6
Sulfur	0.4
Magnesium	0.3
Boron	0.005
Chlorine	0.015
Copper	0.001
Iron	0.020
Manganese	0.050
Molybdenum	0.0001
Zine	0.0100
TOTAL	99.9011

Source: Roller, 1975.

USDA soil scientists have indicated the quantity of nutrients temporarily immobilized each year in chaff, straw, stubble, and roots equals or exceeds the nutrients removed in the grain (14). A 60 bushel wheat crop contains about 100 lbs. of nitrogen in the grain. Normal harvest allows about 30 lbs. of nitrogen to remain in the crop residue in the field after harvest (Table 2). If one-half of this remaining crop residue were also harvested as a cash crop, it would have a soil fertility value of about $2.25/acre on a comparative basis of $300/ton of anhydrous ammonia. The soil fertility value of crop residue may range from $1.20 to $4.00 per ton depending on the type of residue and the fertilizer needs of the soil in the area (6). The values shown in Table 2 are for a specific yield. The greater the yield the greater the nutrient loss when residues are removed.

Nutrients ordinarily supplied or recycled with the organic matter can also be supplied synthetically. The limiting factor is thus the amount of organic or carbonaceous matter which must be maintained, by residue return, to maintain the soil productivity factors associated with soil organic content, to prevent erosion, and to maintain water holding and absorptive capacity in the soil. Replacement of nutrient elements is of course an economic cost which must be borne by the crop residue producer. The fractions of major elements in various plants that may be considered for potential biomass energy resources are indicated on Table 3.

Two factors in modern agriculture have drastically altered the dynamic equilibrium of natural soil formation. First, harvesting grain for food removes some of those nutrients that plants have extracted from the soil, thus curtailing somewhat the recycling process. Second, farming operations have led to accelerated erosion, which selectively removes the upper, more fertile portion of the soil. Agriculture currently maintains soil fertility primarily through the use of commercial fertilization.

Crop residues (above ground stubble and straw after grain harvest) are a substantial reservoir of plant nutrients (10). Table 4 shows the nitrogen (N), phospohorus (P) and potassium (K) in various crop residues as a percentage of that in the residues plus the grain. This is the portion of the nutrients that can be recycled after harvest. Current proposals to use crop residues as an energy resource must consider the consequences of eliminating this return of nutrients and organic matter to the soil.

Table 2

APPROXIMATE NUTRIENT QUALITY
IN CROP RESIDUE

Crop	Yield	N	P	K	Ca	Mg	S	Mn
	bu/ac.	lb/ac.						
Barley	80	24	4	40	14	4	7	0.5
Oat	100	35	8	80	12	15	13	0.4
Wheat	60	30	5	35	9	4	6	0.2

(Values vary greatly with variety, kind of soil, level of management, and season.)

Source: Robertson, 1978.

Table 3

FRACTION OF MAJOR ELEMENTS FOUND IN MAIN PARTS OF PLANTS FOR POTENTIAL BIOMASS ENERGY PRODUCTION EVALUATION

Crop	Plant Part	% of Whole*	(kg nutrient/kg dry matter) N	P	K
Alfalfa:	Whole	100	.0350	.0054	.0282
Corn:	Kernels	40	.0142	.0033	.0037
	Cob	10	.0069	.0160	.0041
	Stover	50	.0099	.0018	.0129
	Whole	100	.0113	.0025	.0083
Potatoes:	Tuber	71	.0155	.0025	.0171
	Aerial	29	.0199	.0020	.0395
	Whole	100	.0168	.0023	.0235
Wheat	Kernels	40	.0220	.0047	.0044
	Straw	60	.0067	.0008	.0087
	Whole	100	.0129	.0024	.0070

* A Dry Matter Basis.

Source: Roller, 1975.

Table 4

PERCENTAGE OF N, P, AND K IN CROP RESIDUES
COMPARED TO THOSE IN RESIDUES PLUS GRAIN

Crop	N	P	K
Barley	30	22	76
Corn	43	41	78
Oats	33	43	84
Wheat	29	15	70

Source: Holt, 1979.

WIND EROSION CONTROL

Those croplands in the Great Plains where crop residues might be removed without exposing the soil to wind erosion have been delineated (16). On the basis of grain-yield data, an estimate of the residues produced per unit of land by crops was made. The mean soil erodibility and climatic factors for each of 29 major Great Plains land resource areas was determined and these factors were used in the "wind erosion equation" to estimate the residues needed to control wind erosion. The residues produced in excess of those needed for soil conservation depend on the kind and amount of residues, soil erodibility, climate, tillage management, and judgment of erosion and degradation hazard. The wind erosion equation, crop acreages, and crop yield data was used to analyze the effects of removing crop residues from the land on wind erosion control in the Great Plains.

The Great Plains include three land resource regions: Northern Great Plains Spring Wheat Region (F), Western Great Plains Range and Irrigated Region (G), and Central Great Plains Winter Wheat and Range Region (H). These regions include 29 major land resource areas (MLRAs) and constitute most of 416 counties in 11 states (Figure 1). The Montana MLRA's are 52 and 53 for northcentral and northeast; 58, 59 for southcentral and southeast areas.

Tables 5 and 6 indicate the crop residue produced in the Montana MLRAs compared with the amount of residues that would be "available" from wide smooth fields after leaving an adequate amount for wind erosion control and without creating a wind erosion hazard of more than 5.0 tons per acre per year. Figures 2 and 3 show areas where crop residues are insufficient for wind erosion control or in surplus for this purpose. The work also involved other combinations of surface roughness and tolerable wind erosions, and determined amounts of nitrogen, phosphorus, and potassium in the crop residues produced in each MLRA.

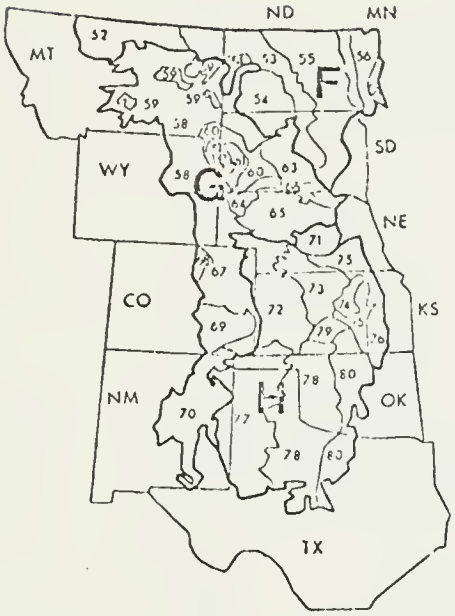

Figure 1. Land resource regions F, G, H, and MLRAs 52-80 in the Great Plains.

Source: Skidmore, 1979.

Table 5

HARVESTED AREA, RESIDUES PRODUCED, AND RESIDUES AVAILABLE COMPARED WITH THOSE NEEDED TO CONTROL WIND EROSION ON WIDE FIELDS OF BARLEY, OATS AND CORN IN THE MLRAs OF MONTANA

	Barley			Oats			Corn		
	Harvested	Residues		Harvested	Residues		Harvested	Residues	
MLRA*	Area (ka)	Produced (t/a)	Available (t/a)	Area (ka)	Produced (t/a)	Available (t/a)	Area (ka)	Produced (t/a)	Available (t/a)
52	605.6	1.0	-0.3	11.2	1.1	-0.2	0.1	1.3	-0.5
58	158.9	1.3	0.3	11.1	1.3	0.3	1.2	2.0	0.4
59	139.7	1.4	0.1	11.7	1.4	0.1	0.2	1.8	0.1
60	13.6	0.9	-0.1	2.9	1.2	0.1	1.8	2.1	0.6

* Major Land Resource Area

Source: Skidmore, 1979.

Table 6

HARVESTED AREA, RESIDUES PRODUCED, AND RESIDUES AVAILABLE COMPARED WITH THOSE NEEDED TO CONTROL WIND EROSION ON WIDE FIELDS OF WHEAT IN THE MLRAs OF MONTANA

	Total Wheat			Continuous Wheat			Fallow Wheat		
	Harvested	Residues		Harvested	Residues		Harvested	Residues	
MLRA	Area (ka)	Produced (t/a)	Available (t/a)	Area (ka)	Produced (t/a)	Available (t/a)	Area (ka)	Produced (t/a)	Available (t/a)
52	1986.4	1.2	-0.2	112.8	0.9	-0.1	247.4	1.4	-0.2
58	451.7	1.4	0.3	22.3	1.1	0.3	59.3	1.6	0.3
59	596.7	1.2	0	38.5	0.9	0	69.3	1.4	0
60	62.3	1.3	0.2	2.4	0.9	0.1	8.8	1.4	0.2

Source: Skidmore, 1979.

Figure 2. Area in the Great Plains where barley residue is deficit and surplus at less than and greater than 1.1 metric tons per hectare (1,000 lb/a) for controlling potential average annual soil loss from wind erosion to 11.2 metric tons per hectare per year (5.0 t/a/yr) on wide, smooth fields.

Source: Skidmore, 1979.

Figure 3. Area in the Great Plains where wheat residue is deficit and surplus at less than and greater than 1.1 metric tons per hectare (1,000 lb/a) for limiting potential average annual soil loss from wind erosion to 11.2 metric tons per hectare per year (5.0 t/a/yr) on wide, smooth fields.

Source: Skidmore, 1979.

Wind Erosion Equation

The amount of wind erosion, E, expressed in tons per acre per annum, that will occur from a given agricultural field can be expressed in terms of equivalent variables as: $E = f(I', K', C', L', V)$ where I' is a soil erodibility index, K' is a soil ridge roughness factor, C' is a climatic factor, L' is field length along the prevailing wind erosion direction, and V is equivalent quantity of vegetative cover (19). The five equivalent variables are obtained by grouping some and converting others of the eleven primary variables now known to govern wind erodibility. Relations among variables are extremely complex. Charts and tables have been developed to permit graphical solutions of the equation. The equation is designed to serve the twofold purpose of providing a tool to (i) determine the potential erosion from a particular field, and (ii) determine what field conditions of soil clodiness, roughness, vegetative cover, sheltering by barriers, or width and orientation of field are necessary to reduce potential erosion to a tolerable amount.

Soil surface moisture affects the rate of soil movement inversely as the square of effective soil surface moisture. Soil surface moisture causes the soil to adhere to itself, thereby decreasing the erodibility of the soil. Residue management affects soil surface moisture and the vegetative cover variables. Residues left to reduce water erosion serve a double function of reducing wind erosion. However, wind and water erosion constraints seldom will be binding in the same place at the same time. The larger amount of residues required will be the amount required to maintain a high level of crop productivity, economically and indefinitely. The factors affecting soil loss by wind erosion are understood well. These factors are similar to those for water erosion and relate principally to the soil's characteristics and wind regimes. Residue management practices are an effective means of controlling soil losses except when wind speeds exceed 20 mph.

WATER EROSION CONTROL

Tillage and plant residue management systems are being more thoroughly evaluated for controlling soil erosion by water in the Pacific Northwest (2). Along with tillage and plant residue management systems, slope length reductions and contouring are important in controlling water erosion on the long, steep slopes in eastern Oregon. These management practices together are described by the slope length, cover and management, and supporting practice factors in the "universal soil loss equation" (USLE).

The Pacific Northwest MLRAs, as a group, have many common features that cause water erosion. Cool, wet winters follow warm, dry summers, a combination that produces sparse vegetative cover in winter, even where agriculture is not intense. Arid conditions in late summer limit crop species to those that mature for harvest early in the summer. The smooth to deeply dissected plains and plateaus have long, steep slopes susceptible to excessive sheet and rill erosion.

Soil erosion estimates by water in the major land resource areas of eastern Oregon have been estimated. Combinations of tillage and crop residue handling, terracing, and contouring were evaluated as control alternatives. Wheat-fallow, especially, and wheat-pea sequences predominated. Soil erosion exceeded tolerance limits in the wheat-fallow sequence on slopes over 20 percent even with all three management inputs. All three management inputs were needed on slopes between 12 and 20 percent. Tillage and residue management, along with contouring, sufficed on slopes less than 12 percent. The three major land resource areas in eastern Oregon (4.8 million acres) produce 1.4 million tons of small grain residues annually, 60 percent of which can be harvested from 88 percent of the 850,000 acres harvested.

Wind and water erosion are the principal causes of loss in U.S. agriculture. the factors affecting water erosion have been researched thoroughly. These factors describe the soil characteristics (slope and erodibility), the amount and intensity of rainfally, and crop management practices. Crop management practices, including residue mulches, are the most important factors that determine soil loss by water erosion.

Residue mulches used to control water erosion serve a double function of reducing soil losses by wind erosion. However, wind and water erosion constraints will seldom be binding at the same place at the same time. The larger amount of residues required will be the binding constraint on productivity maintenance. High levels of productivity can be maintained if soil losses are small becuase soils are constantly being formed. The rate at which soils are formed determines the "soil loss tolerance," the maximum rate of erosion that will permit a high level of soil productivity to be sustained economically and indefinitely.

Two other methods of conservation tillage and management practices are quite common in America agriculture; contouring and terracing. The practice of plowing and planting on surface contours has been effective in reducing erosion. In limited field studies, contouring has provided almost complete protection against erosion from individual storms of moderate to low intensity, but little or no protection from occasional severe storms. Contouring provides its maximum protection on slopes of 3-7%. Contour strip-cropping, a practice in which contour strips of sod are alternated with strips of row crops, has proved to be a more effective practice than contouring alone (7). Terracing with contour farming is more effective as an erosion control practice than strip-cropping because the slope is divided into segments equal to the horizontal spacing. Dividing a slope length into four equal segments cuts the expected rate of soil loss in half.

CROP RESIDUE MANAGEMENT ON SOIL EROSION

A crop residue management study conducted by a team of USDA researchers involved the accumulation of large amounts of data and thousands of mathematical computations, done with the aid of a computer (11). Using the universal soil loss equation (USLE), they delineated those areas from which crop residues could be removed from the soil surface for other uses without erosion exceeding "the soil loss tolerence limit." The permissible limit is a function of the ability of the soil itself to maintain an acceptable level of productivity with varying levels of recycle of residues. This ability varies both with the soil and its location in the country.

The USLE is A = RKLSCP, where A is the computed soil loss, R is the rainfall factor, K is the soil erodibility factor, L is the slope length factor, S is the slope gradient factor, C is the crop management factor, and P is the erosion control practice factor. To calculate residue production, they multiplied grain yields by a straw/grain ratio (Table 7). Residue yield times average nutrient percentages gave the nutrient content in the residues. (Table 2).

Table 7
DRY WEIGHT RATIO OF STRAW TO GRAIN
FOR SELECTED CROP RESIDUES

Crop	Straw/Grain Ratio
Barley	1.5
Corn	1.0
Oats	2.0
Wheat:	
Winter	1.7
Spring	1.3

Source: Larson, 1979.

Effects of Straw Mulch on Soil Temperature

The effects of applying a wheat straw mulch at various rates to a trash-free summerfallow field immediately after seeding spring and winter wheat were studied for 9 years in Alberta, Canada (3). Winter wheat yields of 40 and 50 bu/ac, would yield 4000 and 5000 lbs. of straw/acre respectively. Application rates of 4000 and 5000 lb. or more per acre significantly depressed mean yields of spring and winter wheat, respectively. Straw at rates of 4000 to 5000 lb. completely shaded the soil surface when spread uniformly. Higher rates delayed maturity up to 4 to 6 days, shortened heights of plants, occasionally lowered nitrate production, and had a negligible effect on plant population and percentage protein of grain. Each 1000-lb. increment of bright straw depressed the late-morning temperature in the 8-in. depth of soil by an average value of 0.25^{o} F during the early growth period. The depression increased with the season to a value of 0.65^{o} F by min-June and then decreased to a value of 0.25^{o} F by mid-July, when the crop, in the headed-out stage, almost completely shaded the soil surface.

A quantity of mulch up to 4000 lb. per acre can be used without deleterious effects on the crop. Quantities of 4000 lb. or more should be managed so that the soil temperature depression with complete shading of the soil is avoided.

Crop residue mulches can have detrimental effects on soil productivity. These detrimental effects include but are not limited to (1) reductions in soil temperatures which depress germination rates and delay plant maturity, (2) reductions in nitrate formation, (3) production of substances that are toxic to germination, (4) increases in pesticide requirements, and (5) creation of subtances that increase the potential for plant disease. The effects of items 2 through 5 on crop yields have not been quantitatively separable. Ususally, residues have no deleterious effects with conventional residue management practices.

Effect of Mulches on Water Intake

Crop residue not only reduce erosion and maintain nutrient balances, but also conserve soil moisture. Residues increase water intake by preventing the formation of a compacted layer caused by raindrop impact on bare soil. The most economical treatment for controlling evaporation and soil loss is a crop residue mulch. The effects of straw, gravel, and treated soil mulches on runoff, erosion, and soil moisture depletion have been reported (3). It was found that all of the mulches reduced evaporation and that gravel and straw mulches increased water intake.

Soil moisture is frequently higher in mulched soils than in bare soils as a result of increased water intake and decreased evaporation. The effectiveness of a mulch in conserving soil moisture often overshadows the influences of soil temperature on grain yields. Nitrogen availability to plants is frequently lower under mulch tillage than with conventional plowing. Decreased soil temperature and increased soil moisture under a mulch may contribute to the decreased NO_3 nitrogen content of mulched soil.

The most common methods to maintain soil fertility, conserve soil moisture, and control erosion are mulching, crop rotations, and reduced tillage practices. Crop residue mulches may be scattered across the soil surface or inserted vertically. Mulches increase water intake, reduce evaporation losses, recycle nutrients, and control erosion. Crop rotations control erosion losses and replenish nutrients (10).

Surface mulches using crop residues have advantages and disadvantages that must be traded off to maintain long-term soil productivity. Optimum application rates can be determined for a specific set of management practices and soil types, but also are dependent on the costs of application and the value of nutrients displaced.

Chemical Tillage

Many scientists throughout the nation's western wheat country feel that the chemical tillage system of wheat-fallow-wheat production utilizing herbicides and a "judicious" amount of conservation tillage is only in its infancy. Dramatic

growth is expected in the years ahead (17). It is said to be the most significant, economical, new technique for dryland farming in the Great Plains. Systems that conserve soil and moisture will be the direction of the future because they can increase productivity and stability of production year after year.

According to a Nebraska Extension agronomist, grain growers normally conserve only about 20% to 25% of the moisture that falls during the fallow period. With conservation tillage, or leaving as much residue as possible on the soil surface, they conserve about 40% of the moisture. Common among the farmers who have initiated a chemical tillage system is a combination program involving the use of both herbicides and "conservation" or "sweep" tillage for weed control during the fallow period. With the addition of the herbicides, growers have been provided another tool to aid them in conserving extra moisture. Extra moisture means extra yield.

Many of the Great Plains scientists who have researched this conservation system agree that weed control should begin in the fall of the year so that maximum moisture savings will be possible. That's especially important in the wheat country of eastern Colorado. With a good program beginning in the fall High Plains growers can conserve an additional two inches of soil moisture during the fallow period. Atrazine, with its long residual action, has a requirement for fall application. Also cyanazine (Bladex) is a wise addition for fall application if grassy weeds or volunteer wheat tend to be a problem. If conditions are conducive to grassy weed development, Bladex will improve overall weed control.

Spring weed control is also necessary. Sweet tillage is again, an option. A good system utilizing herbicides during the fallow period should reduce an average of four tillage operations. According to recent estimates, it costs the grower from two and one half to four dollars an acre in fuel costs and equipment wear and tear to till one time. Most experts agree that there is a definite cost advantage in going to the herbicides when several tillage operations are eliminated. They've found that the herbicide programs allow for greater moisture retention in the soil, which generally means greater yields.

Presently, increased flax seed yields more than offset the cost of herbicides to produce relatively weed-free straw. Fertilizer replacement costs incurred

in producing relatively weed-free flax straw are about $2.30 per acre. The 1974-1975 average price of flax straw was about $12.00 per ton, which has sufficient to cover the costs of producing flax straw under normal harvest procedures.

Wheat production in the major wheat producing areas involves large acreages per farm and is machinery intensive. Wheat land is susceptible to rainfall erosion, and particularly in dry years to wind erosion. The latter in particular places a practical limit on the amount of residue which might be harvested for energy purposes, as wheat stubble and straw is managed so as to minimize wind as well as water erosion. With current wheat combining practice, as little as possible of the straw is cut, and residue harvesting would entail a significant deviation from current practice. However, the straw can be readily harvested, after grain harvest, with conventional haying machinery.

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